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**THE DESIGN OF A WESTERN CANADIAN REAL-TIME SYSTEM FOR
INTEGRATED FORECASTING OF BASIN SPECIFIC FLOODS AND LOW FLOWS**

by

**Jeff Whiting
Elaine Wheaton**

SRC Technical Report No. 195

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ABSTRACT

The study identifies the needs of water resource managers for hydrometeorological information and presents a design for an integrated hydrometeorological system for Western and Northern Canada. Floods are high on the list in loss of life, and damage to property. A single flood may now account for \$100 million in direct property losses. It is necessary to improve the flood forecast warning times, particularly for the headwater areas. Flood warnings, issued less than 6 hours before the crest, require the input of automated station, satellite and radar data. Flood warnings, for lead time greater than 6 hours, still require the fine scale network but also require input from complex numerical weather prediction models. For drought forecasting, longer duration forecasts of more than a week are required.

Therefore, the goal of any new forecasting system is to increase the lead time by access to automated digital data, implementation of integrated hydrometeorological data systems, and optimization of the models.

The AES integration system called CLI-GRID (Climate-Grid) should be tested for its appropriateness as the input module to provide the meteorological data to hydrological models used in the study area. The Meteorological Satellite Information System (METSIS) is recommended as the communication system for all data including water levels and flow data, and for output to Teledon.

The best archetype for the proposed Flood Warning Forecast System appears to be the Great Lakes Flood Watch Centre. This centre is funded by the Canada/Ontario Flood Damage Reduction Program. Forecasting system costs range from a low of \$50,000 to a high of \$1 million annually.

Some perceived problems are the use of non-standard automatic stations, priority conflicts between real-time users and operating agencies, merging old data with new, central versus regional data acquisition and dissemination, and cost recovery.

If such a system is installed, flood warning lead time can be increased from 4 to 14 hours for the 18-hour forecasts and from $\frac{1}{2}$ to 2 hours for the flash flood forecast. These improvements translate into an estimated potential reduction in damages to property loss (alone) of \$12 million per year.

EXECUTIVE SUMMARY

The AES and other agencies collect and archive a great deal of site-specific information on precipitation and temperature. A system has not yet been developed to take full advantage of all the available non-standard and non-AES climatological data, and more importantly, the AES radar and other remote sensing data. A system is needed that integrates, manages and disseminates the resultant information particularly for flood and drought forecasting.

As a first step, there is a requirement to identify the characteristics of such a system and to assess what is needed to make such a system successful. This study suggests the directions and the information required to fulfill the data needs and to create the system. In addition, addition, the study results could serve as the basis for an action plan to be carried out over the next two or three years and the development of an integrated watershed hydrometeorologic data base for water resource managers in Western and Northern Canada.

The time is appropriate for this study because of these factors: new sensor capabilities, greater use of automatic stations, and improved communication and modelling capabilities. Through the rapid expansion of the global communication network in Canada, we are now able to rapidly transmit and receive information. Thus, an integrated data system is becoming more practical and possible.

The objectives of the study are to:

1. identify the needs of water resource managers for hydrometeorological information on the scale of a watershed;
2. identify the best ways of meeting those requirements using both standard and non-standard sources of hydrometeorological data and by

assessing ways to analyze the information;

3. present a design for an integrated system which could collect, process, integrate, and communicate the necessary information to water resource managers in Western and Northern Canada; and

4. specify scientific, technical and administrative problems and issues which must be addressed to implement such a system and propose ways for addressing each problem or issue.

Floods and severe weather top the list of causes of socioeconomic loss in Canada. The loss estimates ignore the cost of preparation, monitoring, and forecasting the event and/or protecting people and property. The indirect costs of adjustment to natural hazards are probably much larger than the direct costs. Floods have consistently been the most deadly of the environmental hazards in terms of loss of life in the last three decades. Flood losses have also risen dramatically in the last two decades. Rough estimates for Canada from 1948 to 1974 range in excess of \$100 million per event, not considering inflation.

There are over 200 high risk areas in Canada that have significant flood problems. In recent years the most important trend during the last decade or so has been the growing concern for pre- and post-hazard mitigation. The focus on mitigation stems from the mounting cost of relief and recovery, and is supported by the evolution of hazard and emergency management programs. As part of the Flood Damage Reduction Program, the federal government hoped to obtain further agreement with the provinces on cooperative flood forecasting and warning services, flood protection or acquisition of property easements, and changes in land use.

The Pearse Board of Inquiry recognized the need when it recommended that federal activities be related to compiling hydrological data about flooding and flood risk, constructing flood control works where federal interests are threatened or where damages are likely to be of national significance, and providing emergency and disaster relief. The Board also suggested that remote sensing, satellite communication and other advanced technologies should be explored to economize and improve information in water quantity and quality monitoring systems. The use of experience and expertise of AES was also suggested (Pearse et al. 1985).

The meteorological 'trigger' for hydrological events varies in size, lifetime, and predictability. For example, a severe thunderstorm may cause local heavy flooding in one part of town but its duration and intensity is not easily predicted, quantitatively, for more than an hour or two. On the other hand, the forecast of critically low flows on major rivers is often the result of prolonged drought, where the significant meteorological trigger is the net effect of low precipitation and high temperatures, accumulated over weeks or months. Neither of these hydrological events is easily deduced from synoptic scale forecasts without a finer network of observations or seasonal monitoring and predictive capability. Fortunately, the typical spring flood on large rivers in Canada is the result of heavy rain and snow melt over several days which usually match the scale of the meteorological forecasts.

The CLI-GRID project has taken an important first step towards defining the ability of satellites to estimate areal rainfall provided the time period is not too small.

The best archetype for the proposed Flood Warning Forecast System appears to be the Great Lakes Flood Watch Centre. This centre's objec-

tive is to provide coordinating focal point for all federal activities related to flooding in the Great Lakes through the Great Lakes Water Level Communications Centre and the Great Lakes Water Level Forecast Centre. The Communication Centre collects, develops and disseminates information on lake levels, and related flood and shoreline erosion. The Forecast Centre develops and disseminates forecasts and warnings for the Great Lakes. Fifteen people are allocated full-time through the spring and fall storm season providing 24 hour/7 days per week. This program was funded by the Canada/Ontario Flood Damage Reduction Program.

An excellent hydrometeorological system should integrate, manage and disseminate the information. What is needed is not something radically new but a streamlining of the present input and output methods for meteorological and hydrological data and a mechanism to quickly communicate that information to the present flood forecasting centres in a meaningful and appropriate manner.

Criteria for the proposed system include:

1. the ability to acquire data 24 hours per day from the AES network, automated hydrometeorological stations, weather radars, satellites, manual and other sources as required;
2. the option to select model periods (e.g. 6 hours) and watersheds (basin boundaries) and the initiation of streamflow forecasting functions (flow, precipitation, temperature and calibration) as required;
3. the ability of the system to provide for intermittent requests from forecasting centres for map plotting, data display and program development.

For greater flexibility and ease of development, the system would be divided into modules, each of them being devoted to a specific task.

These modules would be: INPUT, PHYSIOGRAPHY, PRECIPITATION (including snow accumulation and melt), EVAPOTRANSPIRATION, HYDROLOGY (including production and routing), OPTIMIZATION, FORECAST, OUTPUT, and COMMUNICATION. It should have the flexibility to have additional modules added whenever and wherever required. All incoming data would be put into a common data format and all modules would be transformed to a common geo-referenced data base.

The separation of the system into modules allows independent development and replacement of each module. In practice, the only constraints on a particular module would be the type and format of the input and output variables. For the first version of the system, a time step of 6 hours is considered. The longer term objective, however, would be to use a time step varying with hydrologic events.

A considerable number of hydrometeorological parameters are online and available in real time. Additional daily measurements are on-line, however, but are not available in real time. These include 15 minute and hourly rainfall, soil temperatures, and hourly wind runs, for examples. If they were made available on a daily basis, modelling would be improved.

In addition, the following historic information should be in an archive in the system or available on-line: long term records (>30 years) of temperature, precipitation, snowfall and snow cover, hourly or daily sunshine and radiation, extreme daily precipitation, storm analysis (updating required), 100 year persistent dew point temperatures (updated), snow cover frequencies; list of significant storms (updated), evaporation rates as a function of moisture, and runoff as a function of soil moisture. Some additional information would make the hydrological

models more efficient and perhaps more realistic: temporal statistical analysis of precipitation (e.g. what percentage of the total rainfall occurs in the first 24 hours of a 72 hour storm), effect of topography on prairie storms, soil moisture information, continued and better snow survey records, climate change effects on hydrology due to changes in precipitation and temperature, snow melt curves for all stations, snow melt versus temperature (2 per month), soil moisture curves, snow-line or percent of snow left in a basin, and the compilation of climate data as a function of basin (the method prior to 1976).

The 1979 Flood Forecasting Technical Workshop recommended that Inland Waters Directorate, in concert with AES, should conduct detailed sensitivity analysis for each hydrological model that is being used operationally. The analysis would include the determination of the level of error in final predictions because of precipitation, temperature, snow cover and evaporation errors. This analysis could possibly justify better observational networks, and the implementation of radar and satellite technology.

The Pearse Board suggested that remote sensing, satellite communication and other advanced technologies should be explored to economize and improve information in water quantity [and quality monitoring] systems. The use of the experience and expertise of AES was also suggested (Pearse et al. 1985). In order to accomplish the above stated tasks, regional seminars in hydrometeorology for meteorological and hydrological forecasters would help to open paths of communication.

CLI-GRID should be tested to determine whether its is the appropriate model to be implemented for Western and Northern Canada. For the first version of the system, a time step of 6 hours and a grid size of

5 km is recommended, while later versions should use steps varying with hydrologic events. Remote transmission of information and hard-copy are necessary. METSIS is the recommended method to transmit the information among computer systems. For distribution of warnings to users, a system called STAR (Système Télèphonique d'Alerte aux Risque) from France is suggested to broadcast flood warnings over the regular telephone system. The purpose of this system is to broadcast the flood warning to a pre-established list of addressees, according to the risk, its seriousness and area concerned. The system will have to have some built-in redundancy or back-up. As the sophistication of users increases, their demands for accurate and more detailed real-time and historical information will increase.

An improved method of integration and delivering meteorological output to flood forecast centres is the suggested approach. Because water is a provincial responsibility under the constitution, the responsibility for water resource forecasting will continue to reside with the provinces. However, responsibility for flood forecasting is not well defined especially for interprovincial and international rivers. The Canada/Provincial Flood Damage Reduction Program is a mechanism to fund both the research and the implementation. Policies for the provision of this new service will be necessary. The responsibilities for all parties need to be defined.

Quantitative Precipitation Forecast Maps (QPF) for 12 hour periods up to 48 hours are available but flood forecasters require 120 hour forecasts which are presently available but not distributed. The Probability of Precipitation Amount (POPA) forecasts are produced twice per day for six consecutive 12 hour intervals for only 72 stations. For

drought and some flood forecasts conditions, the POPA forecasts need to be extended to 7 days. The possibility of increasing the frequency of issuing the numerical weather forecast must, however, be further investigated. The QPF forecast estimates the occurrence correctly but underforecasts the amount of heavy rain. Since this has serious implications for the hydrological forecast, further research must be considered to improve the QPF capability.

Since the forecast system should transform all data to a common geo-referenced data base, research is needed into appropriate geographic information systems. An interactive procedure is suggested to restructure the original data bank according to hydrological contributing areas. Since the majority of accuracy errors between satellite and ground data are due to geo-referencing errors, further geo-referencing capabilities are required.

The Saskatchewan River is suggested as the test site for the flood and low flow forecasting system because of the calibration work already carried out (Prairie Provinces Water Board 1977), the excellent instrumentation in the basin, and the current Federal/Provincial study (South Saskatchewan Study Board 1986).

In the long-term, new models are probably required which consider: methods for up-dating general hydrologic land cover information; algorithms to determine snow-melt-runoff relationships from snow-covered areas [better snow-melt models], surface soil moisture from microwave data for water budget accounting and linkage to the soil profile, surface temperature for evapotranspiration calculations, vegetation indices or biomass estimates, more work on the Rational method of storm analysis for the Prairies (e.g. storm rotation, adjustment factors), soil infil-

tration rates as a function of snow cover (percentage of basin), information on soil frost (runoff efficiency increases from 10 to 90% with increasing frost), surface temperatures for evapotranspiration, interceptions calculation, and high resolution data for channel networks and overland flow considerations.

Other problems which must be resolved or at least investigated in conjunction with implementation of research into the new system are:

- increases in number and types of automatic stations create acquisition and data distribution problems;
- priority conflicts between real-time users and operating agencies (e.g. requests for special forecasts);
- merging old data with new;
- central data acquisition and dissemination versus regional;
- cost recovery and user pay make initiation of the system difficult;
- warning and advisory better than nothing (silence or withholding information) due to uncertainty;
- longer (3-5) day forecasts have been transferred to the CRAY computer with emphasis placed on day one forecasting.

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1 INTRODUCTION AND RATIONALE

The National Hydrology Research Centre (NHRC) officially opened in Saskatoon in October, 1986. The Canadian Climate Centre (CCC) of the Atmospheric Environment Services (AES) has established a Hydrometeorological Research Division within NHRC and has recently appointed a Division Chief who is now developing this activity giving emphasis to western and northern problems.

This Division is presently identifying the needs of clients and seeking to establish strong ties with scientific organizations in Western Canada which have a capability in hydrometeorology. One major need identified by a number of water resource management agencies involves the provision of accurate estimates of parameters such as precipitation and evaporation on a watershed basis.

While the AES and other agencies collect and archive a great deal of site-specific information on rainfall values and temperature, a system has not yet been developed to take full advantage of all the available non-standard and non-AES climatological data, nor the AES radar and remote sensing data. A system is needed which integrates, manages and disseminates the resultant information.

As a first step, there is a requirement to identify the characteristics of such a system and to assess what is needed to make such a system successful. This study suggests the directions and the information required to fulfill the data needs and to create the system. In addition, the study results could serve as the basis for an action plan to be carried out over the next two or three years and the development of an integrated watershed hydrometeorologic data base for water resource managers in Western and Northern Canada.

1.1 Need for an Integrated Hydrometeorological System

The time is appropriate for this study because of such factors as new sensor capabilities, greater use of automatic stations and personal computers, and improved communication systems and modelling capabilities. Through the rapid expansion of global communication network in Canada, we are now able to rapidly transmit and receive information. Thus, an integrated data system is becoming more practical and possible.

There is also a need for the integration of hydrological and meteorological data from diverse sources. This information would provide an improved set of inputs for hydrological models. Then the models could potentially supply more accurate results to the flood forecasting system.

An improved method of integration and delivering meteorological output to flood forecast centres is required. Policies for the provision of these new services are also required. What would the best policies be? Other questions to be answered are: can both the meteorological and hydrological models reside on the same computer? How should the development of such a system be coordinated?

1.2 Objectives and Scope of the Study

The objectives of the study are to:

1. identify the needs of water resource managers for hydrometeorological information on the scale of a watershed;
2. identify the best ways of meeting those requirements using both standard and non-standard sources of hydrometeorological data and by assessing ways to analyze the information;
3. present a design for an integrated system which could collect,

process, integrate, and communicate the necessary information to water resource managers in Western and Northern Canada; and

4. specify scientific, technical and administrative problems and issues which must be addressed to implement such a system and propose ways for addressing each problem or issue.

1.3 Socioeconomic Impacts of Floods and Low Flow

Periods of floods and low flows (drought) can and have resulted in considerable socioeconomic losses. Improved predictions of floods and low flows could be used to decrease the losses and increase the benefits. A major limitation to accurate model output is the reliable characterization of the initial state of the hydrometeorological system. An integrated hydrometeorological data base could provide a foundation to improve the forecasts. A discussion of the economic benefits of better forecasts of floods and low flows are provided in this section.

Floods and low flows also seriously affect a number of resource activities in Western and Northern Canada. Some of the main sectors affected are hydroelectric power, agriculture, forestry, fisheries, recreation and wildlife. Improved forecasts of hydrological events would, in turn, be favorable to the efficient management of a watershed. This would be especially true if hydrological models communicated effectively with biological and economic models and their predictions (Walters 1975).

Some examples of the economic impacts of drought in the forestry and agriculture sector are provided herein. The 1985 drought in Southern British Columbia led to the worst forest fire season on record. These fires were estimated to cost over \$300 million in timber losses

and fire fighting (Ferguson and Phillips 1986). There were also losses in tourism as tourists were warned to stay away. In the agricultural sector, 1985 marked the second consecutive of severe drought in Western Canada. Direct losses to grain farmers were estimated at \$1 billion (Ferguson and Phillips 1986). In contrast, at the same time 100 km away, copious summer rains in Manitoba left fields too wet to harvest on time. Thus extremes of hydrometeorological conditions continue to be very costly indeed.

Some improvements in the data base have already been made, with good returns. To maximize hydroelectric production and reduce flood damage, an improved climate network in the Ottawa River Basin was designed. A loss reduction of just 1% could result in over \$4 million in savings per year with a benefit/cost estimate of 28:1 (Ferguson and Phillips 1986). Thus, improvements in the data system can result in substantial savings.

Floods are high on the list in loss of life from natural causes (60% in cities), and damage to property (increasing at 5%/y) (Riebsame et al. 1986). Although no comprehensive accounting has been done in Canada or the U.S.A., natural hazards arising from the atmospheric environment cause several billion dollars worth of damage annually in Canada and the U.S.A. For example, in 1954 Hurricane Hazel produced the largest Canadian loss of life due to a flood - 80 people (MacLock 1976). Because of continued development of river floodplains in the U.S.A., a single flood may now account for \$1 billion in direct property losses. The Canadian losses are probably in the order of 10% of the U.S.A. figures (i.e. \$100 million per flood). New development on floodplains in Canada is reduced because of the Flood Plain Reduction Program, but

it is not eliminated.

Floods and severe weather top the list of causes of socioeconomic loss in Canada. The loss estimates ignore the cost of preparation, monitoring, forecasting the event and/or protecting people and property. The indirect costs of adjustment to natural hazards are probably much larger than the direct costs (for example, snow tires and highway snow-control investments are required for dealing with snow storms). Floods have consistently been the most deadly of the environmental hazards in terms of loss of life in the last three decades (Figure 1.1.1). Flood losses have also risen dramatically in the last two decades (Figure 1.1.2). Figures 1.1.1 and 1.1.2 were estimated from the USA data by multiplying by ratio of population (i.e. 0.1). Rough estimates for Canada from 1948 to 1974 range in excess of \$100 million per event, not considering inflation.

The US figures can be verified by comparing known events in Canada. Heavy flooding occurred in the late 1940's, and early 1950's. The 1948 flood in Lower Fraser River flooded 220 km², damaged 2,000 homes and severed the area from the rest of Canada for an extended period of time. In 1950 floods on the Red River affected 1760 km² and caused extensive damage in the city of Winnipeg. 1974 was not a good year for Canada for flooding, with more than \$100 million in losses. 1975 and 1976 were not much better at \$60 million in losses (MacLock 1976). The flood hazard illustrates a glaring, continuing social vulnerability to weather extremes.

Perhaps the most catastrophic of flood damages are the result of dam failures. During the 20th Century alone, more than 8,000 people have perished in more than 200 major dam breaks worldwide. Approximate-

Fig. 1.1.1 ESTIMATED FLOOD DEATHS/10 Y
ESTIMATED FROM USA INFORMATION

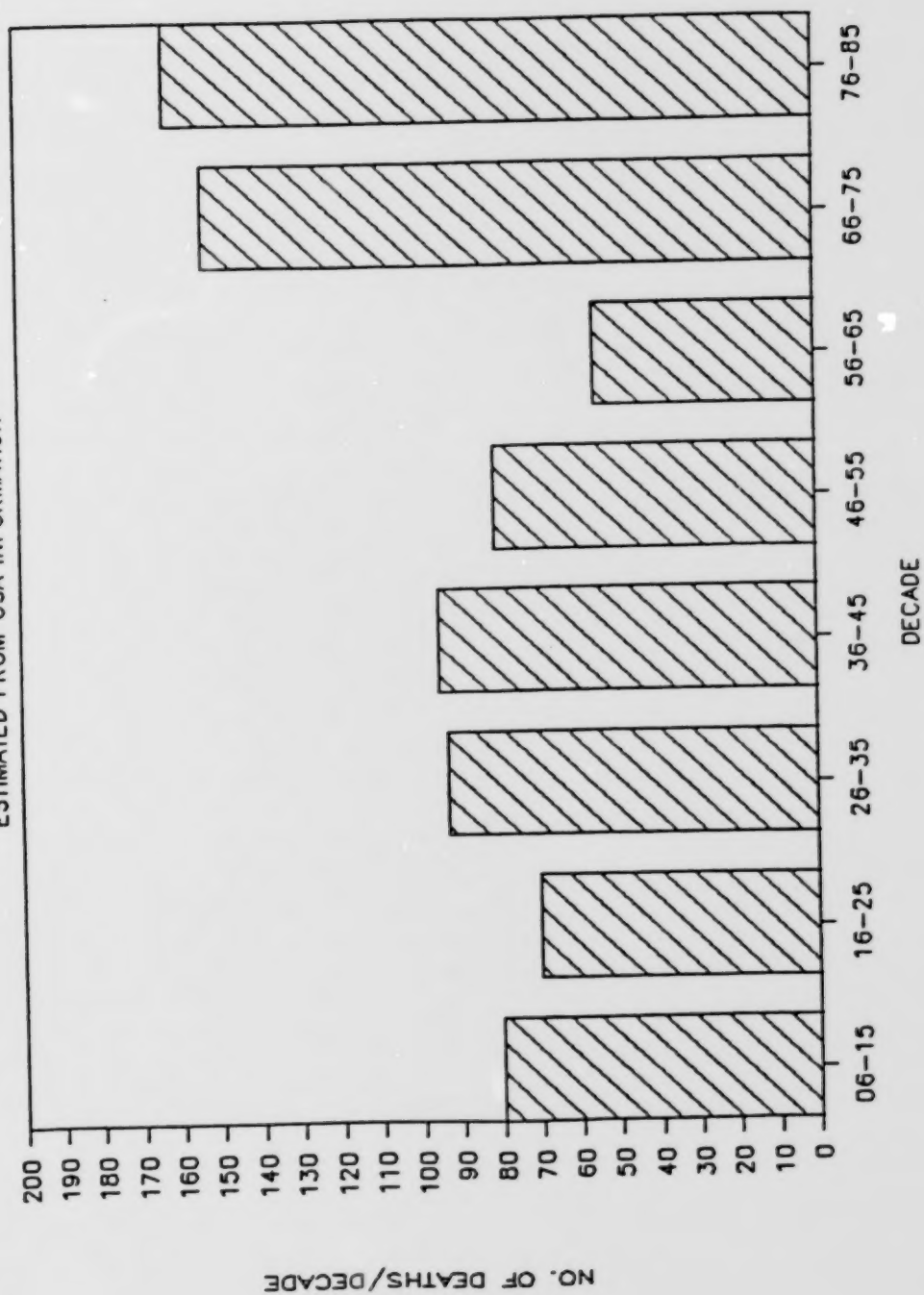
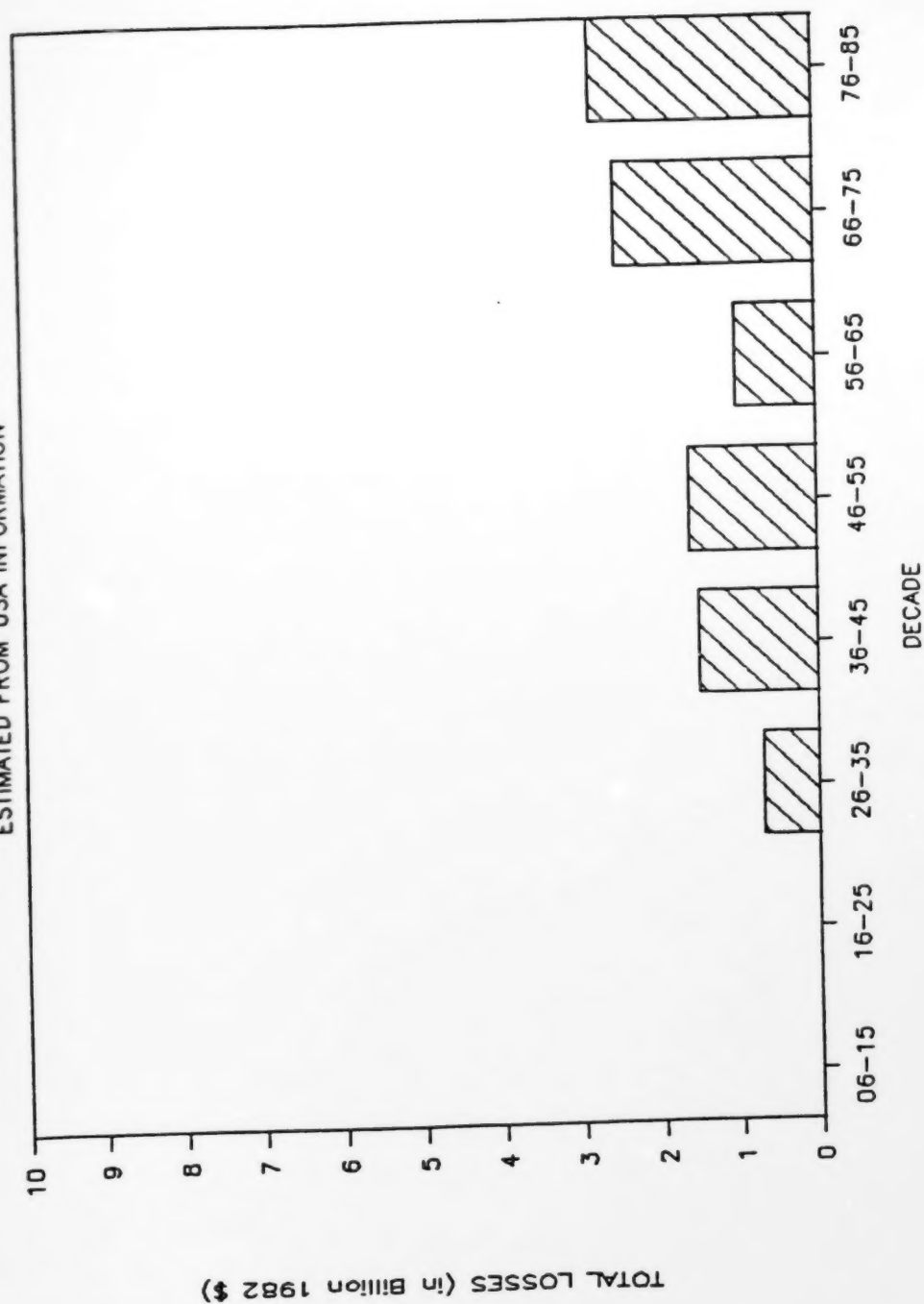


Fig. 1.1.2.2 ESTIMATED FLOOD LOSSES

ESTIMATED FROM USA INFORMATION



ly 3 dams fail every year (Barrett 1986).

In the U.S.A., more than 70% of flash flood warnings have less than one hour lead time (Baldridge et al. 1982). More than 50% of the flash floods have no flood warnings issued -- the flood is already occurring. On the average in the US, only a four hour lead time can be provided for an 18 hour flood event and $\frac{1}{2}$ hour lead time for 6 hour events (Baldridge et al. 1982). The above statistics indicate that the current capability in the US and probably Canada is less than sufficient and needs improving.

There are over 200 high risk areas in Canada that have significant flood problems (MacLock 1976). In recent years the most important trend during the last decade or so has been the growing concern for pre- and post-hazard mitigation (Riebsame et al. 1986). The focus on mitigation stems from the mounting cost of relief and recovery, and is supported by the evolution of hazard and emergency management programs. As part of the Flood Damage Reduction Program, the federal government hoped to obtain further agreement with the provinces on cooperative flood forecasting and warning services, flood protection or acquisition of property easements, and changes in land use.

At present, the NWT and all provinces except Alberta, British Columbia, and Prince Edward Island participate in the flood reduction program (Indian reservation land is included) (Pearse et al. 1985). In 1985-86, Environment Canada allocated \$9 million to this program but this amount is decreasing every year (Pearse et al. 1985).

The Pearse Board of Inquiry recognized the need when it recommended that federal activities be related to compiling hydrological data about flooding and flood risk, constructing flood control works where federal

interests are threatened or where damages are likely to be of national significance, and to providing emergency and disaster relief. The Board also suggested that remote sensing, satellite communication and other advanced technologies should be explored to economize and improve information in water quantity and quality monitoring systems. The use of experience and expertise of AES was also suggested (Pearse et al. 1985).

1.4 Study Need

Since the flood and low flow loss estimates often ignore the cost of preparation, monitoring, forecasting the event and/or protecting people and property, the next step should be to determine what these costs are in order to justify operating the proposed system. The impact of flood and drought events illustrate a noticeable, continuing social vulnerability to weather extremes.

Advanced technologies and capabilities as well as existing expertise should be fully utilized. The Pearse Board suggested that remote sensing, satellite communications and other advance technologies should be explored to economize and improve information in water quantity and quality monitoring systems. The use of the experience and expertise of AES was also suggested (Pearse et al. 1985).

An improved method of integration and delivering meteorological output to flood forecast centres is a recommended approach. Research questions that need to be answered include: Whether both meteorological and hydrological models can be optimized so as to run on the same computer?; Is a joint federal-provincial committee one approach to a co-ordinated development of a forecast system based on joint models?

Thus the need for this study evolves from a combination of such

factors as the continuing severe socioeconomic losses, the development of advanced technologies, the trend towards automatic data collection, and the opportunities behind integration of the standard and non-standard and newer data bases.

2 PHYSICAL CHARACTERISTICS OF FLOODS AND LOW FLOWS AND THE RELEVANCE TO FORECASTING

2.1 Introduction and Definitions

The physical characteristics of floods and low flows are useful in defining the hydrometeorological system requirements and attuning the system to forecasting requirements. This is the reason for providing the definitions and descriptions of floods, low flows and forecasts that are given in this section.

A forecast is a statement of expected future occurrences, of what is predicted and is based upon the present knowledge of the states and the effects of meteorologic, hydrologic, and physiographic conditions.

A flood is a condition that occurs when water overflows the natural or artificial confines of a stream or other body of water, or accumulates by drainage over low-lying areas. Flood forecasts contain predictions of stage, discharge, time of occurrence, and duration of a flood, especially peak discharge at a specific point on a stream, resulting from precipitation and/or snowmelt (WMO 1974). In general, it is provided only when needed (Kite 1974).

A flood warning is defined as advanced notice that a flood may occur in the near future at a certain location or in a certain basin (WMO 1974). A flood is usually a rapid rise in water level in a stream to a peak from which the water level recedes at a slower rate. A flash flood is defined as a flood of short duration with a relatively high peak discharge.

There is no sharp distinction between a flood and flash flood. However, the following descriptive list narrows the window for a flash flood: short lived, local in nature, less than 12 hours between causation and event, and heavy precipitation (a duration less than 2 hours).

Flash floods are generally associated with watersheds with large impervious areas, steep slopes, and with convective storms. Thus major disasters can occur where large cities are located close to mountains.

In contrast, a drought is a period of abnormally dry weather that is sufficiently prolonged for the lack of water to cause a serious hydrologic imbalance (i.e. inadequate soil moisture, water supply shortage, etc.) in affected areas. Drought severity depends upon the degree of moisture deficiency, the duration, and (to a lesser extent) the size of the affected area (Huschke 1959).

Drought warnings are useful if they provide information on volume of water available and the distribution of the water. The forecast of water availability often totally controls the opportunity for industrial development of a region. Warnings could also be effectively used to plan for the optimum management in other sectors as well.

2.2 Time and Space Aspects of Extreme Events

2.2.1 Meteorological Phenomena

The meteorological 'trigger' for hydrological events varies in size and lifetime. The size and lifetime are among the factors that determine the predictability of the phenomena. For example, a severe thunderstorm may cause local heavy flooding in one part of town but its duration and intensity are not easily predicted, quantitatively, for more than an hour or two. On the other hand, the forecast of critically low flows on major rivers is often the result of prolonged drought where the significant meteorological trigger is the net effect of low precipitation and high temperatures, accumulated over weeks or months.

Neither of these hydrological events is easily deduced from synop-

tic scale forecasts. For example, without a finer network of observations the severe, but local thunderstorms may not be detected. Also without seasonal monitoring and predictive capabilities, early warning of droughts are less accurate. Fortunately, the typical spring flood on large rivers in Canada is the result of heavy rain and snow melt over several days and over large areas. So this event usually matches the scale of the meteorological forecasts (Hogg et al. 1985) and the information base is more suitable for the forecasting of this event.

The mismatch of the space scale of some hydrometeorological events and the network that provides information for the forecasting of the events is often pronounced. The overall density of precipitation gauges in the basic Canadian federal network is 2.6 per 10,000 km² (Figure 2.2.1). This is roughly 25% of the spatial densities in countries such as India, Mexico, U.S.A., and China (Ferguson and Phillips 1986).

Another determinant of the usefulness of the network is its spatial uniformity. The geographic distribution of federal climate stations is far from uniform, as illustrated in Figure 2.2.2. In the southern fringe of the country, within 500 km of the Canada/U.S.A border, the network density is generally within the acceptable density range recommended by the World Meteorological Organization (WMO 1981). In the remainder of the country, however, the level of density is much lower.

The network inadequacies are exacerbated by closures or changes in the stations' operations. In recent years a significant number of airport observing sites have either been closed, reduced in hours of operation or automated. The problem is that weather does not take a nocturnal holiday. In fact, some significant floods occur at night. Most flash flood deaths occur at night (Mogil 1986). Yet fewer AES personnel



Figure 2.2.1 Precipitation gauge density
(gauges per 10,000 km²)

Source: Ferguson and Phillips (1986).

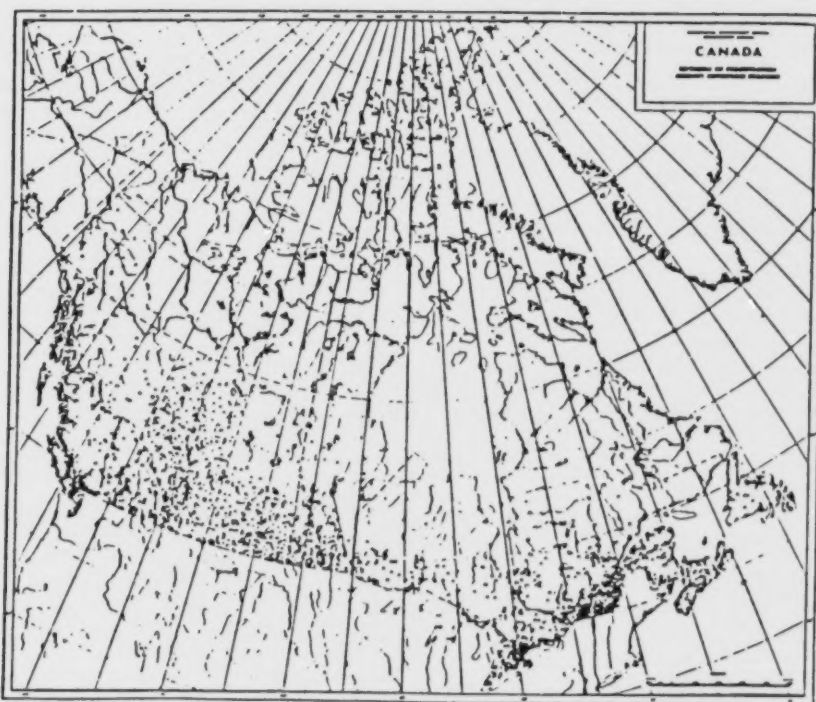


Figure 2.2.2 Network of AES precipitation stations.
Source: Ferguson and Phillips (1986).

are available to work night or overtime. So not until the dawn's light are the movements of the clouds and the positions of the fronts and thunderstorms determined.

To compound the problem of night observations, the usefulness of satellites and radar at night is diminished from daytime. Radar suffers ground clutter problems. For satellites there is less contrast between low cloud and ground temperatures (Mogil 1986) and the discrimination between low cloud and ground can be difficult. So even the new technology needs advancement in order to make a contribution here.

The relative importance of significant meteorological parameters relative to hydrological problems are given in Table 2.2.1. On the short time scale, rainfall may be the only important parameter while temperature, humidity, wind, evaporation and radiation, are secondary in producing accurate streamflow forecasts.

The difficulty in forecasting various meteorological events can be appreciated by comparing the maximum lead times associated with each hydrological event. Lead times range from under two hours for quantitative forecasts of heavy rain to two to three months for quantitative indications of large scale droughts (Hogg et al. 1985). For timing of maximum monthly flow in major prairie streams, the most important parameter is the condition of the winter snow pack.

The importance of defining the needs of the flow forecast system based on the strengths of the meteorological input is clear. In designing a flow forecasting system the identification of limitations of the meteorological network are often overlooked. Also, now that satellites are providing meteorological information as well as the traditional ground networks, it is of interest to examine the time and space scales

Table 2.2.1 Streamflow Forecasting Problems and Meteorological Triggers.

Hydrological Problem	Meteorological Trigger	Size of Trigger km ²	Maximum Forecast Quantity	Lead Time Quality
1. Flash floods				
a) heavy rain on saturated soil	thunderstorm	10	2 hours	12 hours
b) moderate rain on frozen ground	synoptic or meso-scale rain storm	100 - 1000	24 hours	48 hours
c) ice jam	sudden thaw and light to moderate rain	10,000	3 days	5 days
2. "Hybrid" floods	moderate to high snowmelt and rain-fall over 1-2 days	10,000	24 hours	2 days
3. Annual Maximum Discharge for Water Supply Regulation	heavy winter snow-fall and onset of spring thaw	continental	2 weeks	1 month
4. Annual Minimum Discharge for Water Supply Regulation	drought (prolonged heat and dryness)	continental	1 month	2-3 months

Source: Hogg et al. 1985.

of satellite information.

Weather satellites measure phenomena of interest to water resources managers (Figures 2.2.3 and 2.2.4). For example, sequential or repetitive views yield global cloud maps and permit the tracking of storms and the associated precipitation. Radiometric and spectrometric measurements provide quantitative values of atmospheric and surface temperatures, moisture and ozone. The resolution of sensors on-board these satellites and their frequencies of observation must be matched to the space and time scales of the meteorological and hydrological event.

Phenomena with a time scale of minutes to hours (e.g. tornadoes) are difficult to monitor as they require observations with short time intervals. Such short period monitoring requires a very large number of orbiting satellites, or a stationary, geo-synchronous satellite. The GOES Satellite provides 30 minute repeat cycles over large areas (60° latitude and 75° longitude), but its resolution at Canadian latitudes is only 8 km. The NOAA satellite is a polar orbiter; however, only one satellite in orbit is guaranteed (although there are normally 2 in orbit). With one in orbit, 12 hour coverage (i.e. one day and one night pass) is possible with 1.1 km resolution. The land observation satellites, Landsat and SPOT, have 10 m to 60 m resolution and 14 to 16 day cycles. The French satellite, SPOT, can be pointed 7.5° off vertical (nadir) with a 48 hour notice. The monitoring and modelling must therefore be tuned to the time scale of the phenomena.

As a result of the frequency of orbit and the degree of resolution of the satellites, only meso- and macro-scale events can be tracked from space in the foreseeable future (Figure 2.2.3). This includes such phenomena as thunderstorms, hurricanes, monsoons, and droughts. The

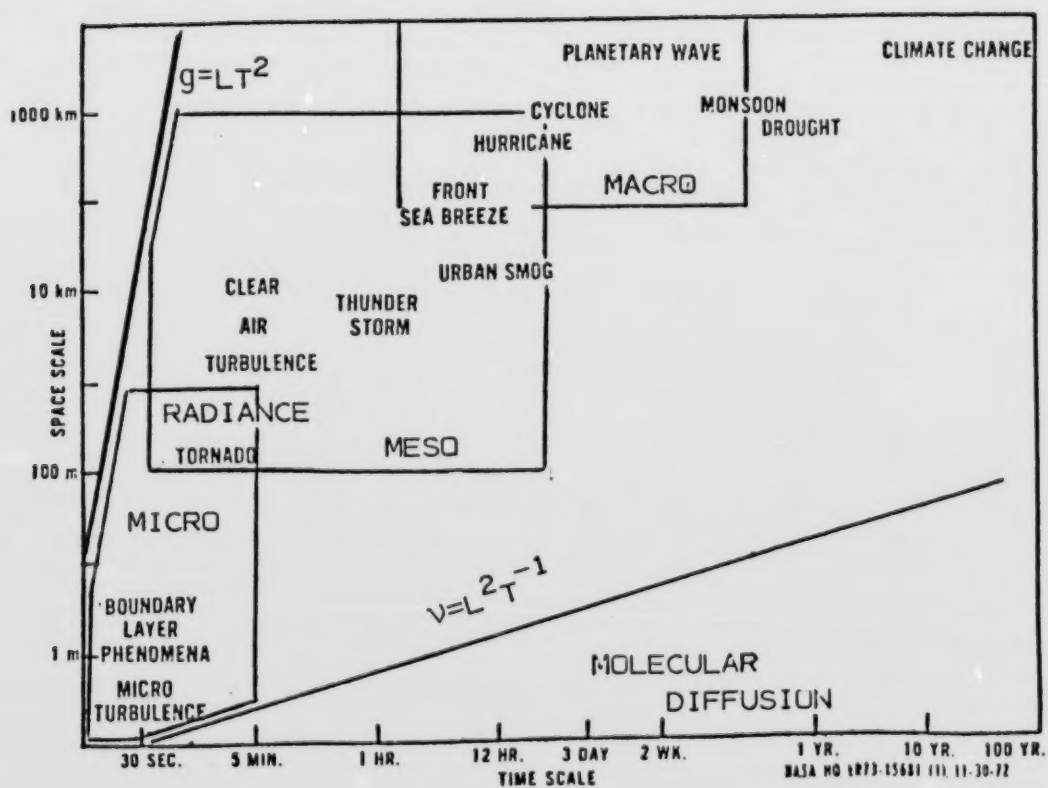


Figure 2.2.3 Time and Space Scales of Meteorological Phenomena

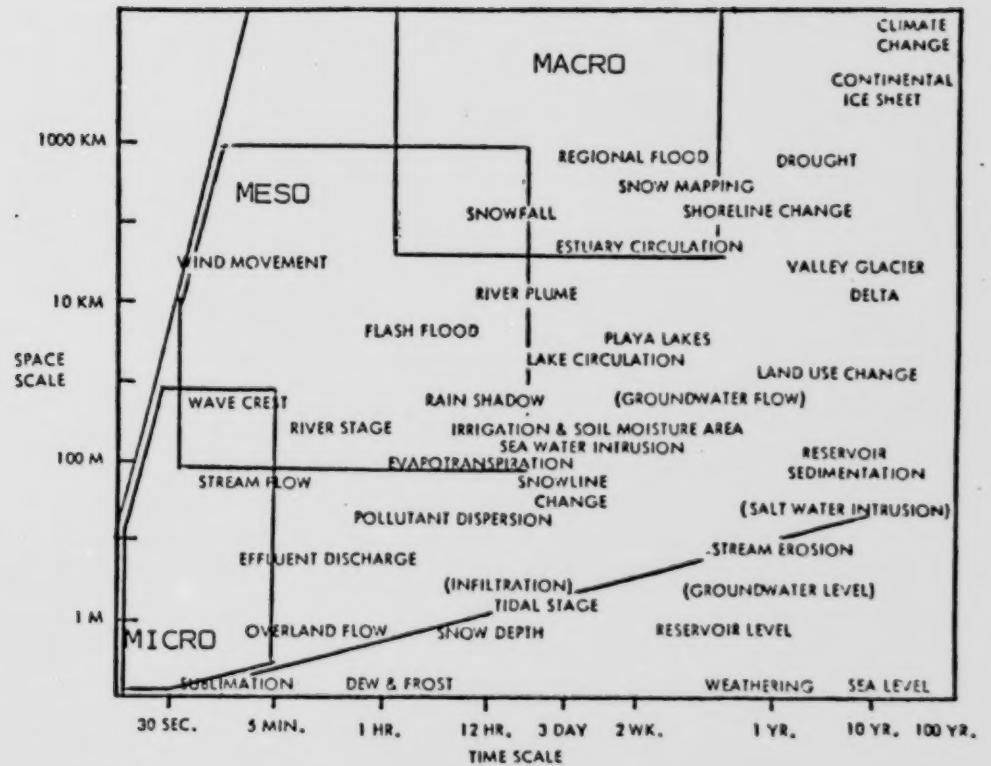


Figure 2.2.4 Time and Space Scales of Water Resources Phenomena

Taken from Remote Sensing and Management by Thomson, Lane & Csallany, AWRA, 1974.

GOES (Geostationary Operational Environmental Satellite) series are suitable only for phenomena in the middle meso-scale and above. The NOAA (National Oceanic and Atmospheric Administration) satellite series is good for the upper meso-scale and greater while Landsat and SPOT are fine for the upper macro-scale.

In summary, both the ground and satellite networks have time and space limitations in their suitability to provide the necessary information to a hydrometeorological data base.

2.2.2 Hydrological Phenomena

The same information regarding space and time scales as for meteorological phenomena can be obtained from Figure 2.2.4 for hydrological phenomena. Table 2.2.1 gives examples of streamflow forecasting problems and the meteorological triggers. Similar monitoring problems and potentials arise from these characteristics. For example, the GOES satellite is capable of providing information for the flash flood and snow cover aspects of the water management needs. The NOAA satellite data capability starts with snow cover information and includes regional floods. The Landsat and SPOT satellite are suitable for monitoring river plumes, lake circulation, land use change, drought and climate variation end of the spectrum of events.

Other problems with the traditional monitoring of hydrological resources often include inaccessibility, especially of such areas as river system headwaters. Precipitation falling on the headwaters area often provides the primary source of water. So monitoring of hydrometeorological conditions in the headwater is crucial. Remote sensing is certainly a means of dealing with the accessibility problems.

Another problem with traditional networks is that of obtaining areally integrated data. Remote sensing inherently provides areally integrated data. Synoptic scenes repetitively covered in digital format, offer the needed data, as well as a means for improving predictive models.

Satellite relay systems are of also of assistance in gathering conventional observations from all over the globe and expediting the speed with which data is obtained from large areas. The use of remote sensing encourages uniformity in the types of measurement instrumentation as well as time and area of observation.

2.3 The Implications of Forecasting for Hydrological Uses

Neither floods nor drought are easily deduced from synoptic scale forecasts without a finer network of observations or a seasonal monitoring and predictive capability. More attention must be paid to the identification of limitations in the hydrometeorological network. The implications of the differences in scales between hydrology and meteorology events and the extent to which meteorological forecasts can be usefully applied must be appreciated. These limitations and methods of dealing with the limitations must be communicated to the hydrologist by an agency such as AES.

In much of Western Canada the climatological network density is less than acceptable. To provide data in this sparse network, satellite data is recommended. NOAA data will have to be used in the proposed western and northern Canada system.

Other research and development areas that have been identified in the section are such as: drought forecasts, methods to offset network

limitations, automated processing of data, the integration of conventional and non-conventional data such as remote sensing information, the provision of night-time data (e.g. how to observe the temperature difference during the night between cloud and the ground), and the forecasting the onset date of spring melt.

Before a flood warning system can be implemented, we need to know the location of flood prone areas, and the location of headwater forecast points. Where the time between the headwater forecast point and the flood prone area (crest time) is less than 6 hours, a flash flood warning system is required (Baldrige et al. 1982). For each of these headwater forecast points, where the crest time is between 6 and 18 hours a headwater flood warning system will be required. Beyond 18 hours, a main stem flood warning system is required. Thus locations and the prioritization of areas that are sensitive to flood and drought as well as the time framework of their sensitivities are important to determine.

3 RELEVANT WORK AND LITERATURE

Relevant work is of two main types. The first type concerns meteorological examples and the second are hydrological examples. Harnum (1984) gives an excellent review of deficiencies for today's measurement technologies and of guidelines for operating flood forecasting systems and centres. The reader is directed to her report for further details.

3.1 Meteorological System Examples

In order to deal with the fast response of small watersheds and to lengthen warning times in larger watersheds with slower response as dominated by snow melt, recourse must be made to meteorological forecasts (Hogg et al. 1985). These often involve the extraction and compilation of non-standard observations from data bases and adaptation of forecasts from numerical weather predictions products.

In the case of the St. John River Forecast Centre the numerical forecast goes directly into the flow forecast model operated at the centre. The products can be grouped into three categories based upon the length of the forecast period: 1) 0 - 6 hours; 2) 6 -24 hours; and 3) more than 24 hours. The first requires the input of satellite and radar data. The second still requires the fine scale detail but also requires the storm development and motion only available from complex numerical weather prediction models.

AES is presently issuing 5-day meteorological forecasts of air temperature and precipitation. In the US and Europe, an extended 5 day average is also available for days 5 through 10 (Yacowar 1987). This extended forecast is needed in Canada for hydrological forecasting. AES is also processing near real-time water budgets for approximately 300

synoptic stations across Canada and northern U.S.A. Derived components from the model are estimates of evapotranspiration, soil moisture, snow pack water equivalents and snow melt. These water budget components are accumulated and averaged over a seven-day period and provided in tabulated and map form within 36 hours of the end of the period (additional details are given in Appendix E).

Since Thiessen polygon techniques are often used to provide areal estimates, the size of the error depends to some extent on the rainfall gradients produced by each storm and not greatly on either the size of the area or the number of polygons associated with the area. The Thiessen technique gives errors of a few per cent for wide-spread precipitation duration rates but as much as 70% for convective showers (Dumont 1983).

The US National Weather Service produces a Limited Fine Mesh Model (LFM) while Canadian Meteorological Centre (CMC) runs a Spectral model. CMC puts out Quantitative Precipitation Forecast Maps (QFP) for 12 hour periods up to 48 hours. Forecasts for up to 120 hours are presently available but not distributed. In light rain situations, the forecast over-estimates and vice-versa for heavy rain. This problem has serious implications for the hydrological forecaster. The under-forecast of precipitation may cause under-estimation of flood potential. In terms of management of errors and focus on problems, the error in precipitation can be higher in light rain and lower in the heavy rain situations.

The Probability of Precipitation Amount (POPA) forecasts are produced twice per day for six consecutive 12 hour intervals for 173 stations (soon to be extended to 5 days if the model is good enough after testing [Yacowar 1987]). The probability of precipitation is given in

three ranges: 0.2 to 2 mm; 2 to 10 mm; and greater than 10 mm. (Further detail and accuracies of these forecasts are given in Appendix E.) This includes three season forecasts for 200 stations [summer, winter and shoulder seasons](Yacowar 1987) with ranges from trace to 2 mm, 2 mm to 10 mm and 10 mm and above (Hogg et al. 1985).

The USA also has a program called the Joint Agricultural Weather Facility (Operational Assessment Program). This is a co-operative effort of the Climate Analysis Centre, National Meteorological Centre/National Weather Service/NOAA and the World Agricultural Outlook Board, and the U.S. Department of Agriculture. The staff consists of meteorologists (for global synoptic weather analysis, interpretation of meteorological satellite data, and management of global weather data bases and products) and agricultural meteorologists who merge these data with historical weather analyses and agronomic information to evaluate crop responses.

Daily summaries of global precipitation and temperature are available from NMC Computer Facility, surface- and upper-air charts, polar orbiting satellites, GOES, METEOSAT and GMS (Geostationary Meteorological Satellite) images, and automated near-real-time meteorological products from CADB. This daily monitoring of station data, synoptic weather and satellite cloud patterns allows close scrutiny of regional agricultural weather before daily, weekly and monthly weather summaries are compiled for future analysis (Motha et al. 1986).

NASA has a relevant and powerful data system termed the Pilot Climate Data System (PCDS). The PCDS manages surface and satellite data sets through its interactively and in an online fashion. Its integrated software modules provide a common format for inventoried data, allowing

subsequent manipulation and graphical analysis among data sets (Olsen 1987).

AES has an on-going pilot study called CLI-GRID (Climate-Grid) involving the development of data integration for a few selected climate parameters and to examine the utility of the resulting gridded data sets in a specified area of southern Ontario and Quebec. Conventional and remote sensing data are used and mapped to a common geo-referenced data base. The data are then transformed into grid square estimates (for each parameter) using objective analysis schemes, radar plus gauge rainfall estimates, satellite temperature or rainfall estimates, etc. (Hogg 1986).

The CLI-GRID project has taken an important first step towards defining the ability of satellites to estimate areal rainfall provided the time period is not too small. For the test data-set both the correlation coefficient and the critical success index improved as the level of sophistication of the satellite technique increased. Of the three techniques tested (control, NAWT [Negri, Alder, and Wetzel technique], and Rainsat), the Rainsat technique compared most favorably with the rain gauge and radar estimates of precipitation (Hogg et al. 1986).

3.2 Hydrological System Examples

Hydrological data systems are in the initial phases of using remote sensing information. Few studies, however, have determined the benefit/cost ratio of using remote sensing in hydrological forecasting. Remote sensing data have been reported to have a large advantage over conventional data except for very small basins (Rango 1985) (See Appendix C for more detail). A projected benefit/cost for snow-cover data is 75:1

(Rango 1980). If the HEC-1 hydrological model and Landsat data were used, the benefit/cost was 4:1 on basins larger than 25 km² (Rango et al. 1983). HEC-1 effectively produces peak flow calculations and SSARR (SRM) model produces highly accurate snow-melt-runoff simulations around the world (Rango 1985).

Comparison of hydrological forecasting errors for test basins in the U.S.A. resulted in a 15% error to actual flow for conventional techniques and 10% error for remote sensing using Landsat (Rango 1985). During drought trials both conventional and remote sensing data had large percentage errors but small errors in volume (Rango 1985).

Flood forecast systems have been set-up in Canada. These systems have been incorporated at the Great Lakes Flood Watch Centre at Burlington, New Brunswick Flood Forecast Centre, ALCAN Corporation Flood Forecast Centre (Saguan-Lac St. Jean) and the Great Lakes Environmental Research Laboratory (GLERL). Harnum (1984) gives an excellent review of deficiencies for today's measurement technologies and provides guidelines for operating flood forecasting systems and centres.

The estimated costs of operating these centres is given in Table 3.2.1. A typical forecasting centre cost could vary from a low of \$50,000 to a high of \$1 million annually depending upon the degree of sophistication and size (Environment Canada 1986). However, none of the above centres contain the sophistication proposed by this report.

The best archetype for the proposed Flood Warning Forecast System appears to be the Great Lakes Flood Watch Centre. This centre's objective is to provide coordinating focal point for all federal activities related to flooding in the Great Lakes through the Great Lakes Water Level Communications Centre and the Great Lakes Water Level Forecast

Table 3.2.1 Unit Costs for Various Components of a Flood Forecasting Centre.

Item Description	Estimated Unit Cost	
	Capital	Operation
1. Meteorological Data		
a) Climatic Stations:		
Manual	\$ 600.00	\$ 1,300.00
DCP	15,000.00	5,000.00
b) Class A Stations	35,000.00	5,000.00
c) Synoptic Stations:		
Manual	20,000.00	75,000.00
DCP	70,000.00	5,000.00
d) Radar		500.00/month
2. Hydrometric		
a) Telemark	40,000.00	10,000.00
b) DARDC	40,000.00	10,000.00
c) DCP	49,000.00	10,000.00
3. Snow Surveys		
a) Field Snow Courses	500.00/day	
b) Aircraft	338.00/20 km flight lines	
c) LMAS Satellite Analyses	300.00/image	
4. Land Cover/Use		
a) Landsat	1,000.00-2,000.00/image	

Source: Environment Canada (1986).

Centre. The Communication Centre collects, develops and disseminates information on lake levels, and related flood and shoreline erosion. The Forecast Centre develops and disseminates forecasts and warnings for the Great Lakes. Fifteen people are allocated full-time through the spring and fall storm season with a 24 hour/7 days per week. This program was funded by the Canada/Ontario Flood Damage Reduction Program.

3.3 The Need to Advance Beyond the Present Systems

In order to deal with the fast response of small watersheds and to lengthen warning times in larger watersheds with a slower response, recourse must be made to meteorological forecasts. At the moment, obtaining all of the necessary forecasts is a problem. For example, flood forecasters require the QPF 120 hour forecasts which are presently available but not distributed. There is of course a reluctance to release new forecast products before verification is completed.

The QPF forecast estimates the frequency correctly but under-estimates the heavy rain. This problem has serious implications for the hydrological forecaster and changes must be considered. Meso-scale forecast model improves are required before real improvements can occur. For drought and some flood forecast conditions the POPA forecasts need to be extended to 7 days.

Other advancements can also be made. The degree of accuracy of the forecast and indeed of the input variables should be communicated to the hydrological forecasters. Also the hydrometeorological inputs could be more closely matched in time and space to the type of flood or drought under consideration, where possible.

4 AN INTEGRATED HYDROMETEOROLOGICAL SYSTEM

An excellent hydrometeorological system should collect, integrate, manage and disseminate the required information. What is needed is not something radically new but a streamlining of present input and output methods for meteorological and hydrological data and a mechanism to get that information to the present flood forecasting centres in a fast, meaningful and appropriate manner. The system would consist of the appropriate complementary combination of people, software, and machines.

Criteria for the proposed system include:

1. the ability to acquire data 24 hours per day from the AES networks, DCP, weather radar, satellite, manual and other sources as required;
2. the option to select model periods (e.g. 6 hours) and watersheds (basin boundaries) and initiation of streamflow forecasting functions (flow, precipitation, temperature and calibration) as required; and
3. the ability to provide for intermittent requests from forecasting centres for map plotting, data display and program development.

4.1 General Structure of the System

For greater flexibility and ease of development, the system would be divided into modules, each of them being devoted to a specific task. These modules would be: INPUT, PHYSIOGRAPHY, PRECIPITATION (including snow accumulation and melt), EVAPOTRANSPIRATION, HYDROLOGY (including production and routing), OPTIMIZATION, FORECAST, OUTPUT, and COMMUNICATION. The system should have the flexibility to have other modules added whenever and wherever required. Incoming data would be put into a common data format and all modules would be transformed into a common

geo-referenced data base.

The separation of the system into modules allows independent development and replacement of each module. In practice, the only constraints on a particular module would be the type and format of the input and output variables. For the first version of the system, a time step of 6 hours is considered. The longer term objective, however, would be to use a time step varying with hydrologic events.

The complete discussion for the integrated system can be found in Appendix A. A summary is provided in the remainder of this section.

The objective of the INPUT module is on-line retrieval and quality control of conventional meteorological and hydrological data as well as less conventional data such as remote sensing data from satellites and meteorological radars. Accurate and timely data would be the basis of the whole system. The data should be transformed into a common data format for ease and speed of access. Accessibility of the data is very important. Data archives would also be required. This would also be needed to feed other networks as well. Quality control procedures would be used to identify report errors. These error reports should include expected errors and confidence limits.

All factors related to basin characteristics would be included in the PHYSIOGRAPHY module. This module would include information such as terrain elevation, slope, aspect, soils, drainage and land-use. A 5 x 5 km grid size should be used initially, but the size could be changed as required.

The PRECIPITATION module prepares precipitation maps and calculates areal amounts by comparing rain gauge and radar data, if the latter are available. Information is obtained from the INPUT module on radar loca-

tion and size of the radar pixel and the location and shape of the basin is automatically retrieved from the PHYSIOGRAPHIC module. Rainfall estimation from integrated satellites, radar and rain gauge data would use an adaptation of the CLI-GRID method. The advanced form of the Precipitation module would be capable of using all existing types of meaningful rainfall estimates.

The EVAPOTRANSPIRATION module is next. Actual and potential evapotranspiration would be obtained for each grid cell or contributing area through the use of various estimation methods depending upon the required accuracy of the output and the availability of input variables.

The HYDROLOGICAL module uses hydrological models to provide the general water routing forecast. The basin should be divided into contributing areas as determined by aggregating grid cells as a function of land-use, soil-type, topography, and drainage pattern.

Usually, distributed models are very complicated and use too much computer time so calibration of the selected hydrological model needs an OPTIMIZATION module to increase its speed. The best method, given the CLI-GRID model, is a coarse grid search to determine the broad area of minimum standard error followed by a search for local optimum or flow (Kik 1978). A sensitivity analysis should be done of the input parameters to find out which parameters have the most effect on flow simulation on an on-going basis.

The magnitude of the flood crest and arrival time at important sites would be calculated by the FORECAST module. The forecasting normally begins before the flood begins. Since no model is perfect and errors are also associated with streamflow measurements, up-dates with the latest information would be necessary. The target would be the same

for both short-term and long-term forecasting. The possibility of updating the initial state of the variables should also be examined (Fortin 1985).

A model for daily forecasting of streamflow would have to be run in a minimum of time with the available data. The model has to be developed so as to make maximum use of remote sensing data but it should also be able to run when remote sensing data is not available. The model should run on as many basins as possible - not only on well-instrumented research basins.

The OUTPUT module displays any result or even the values of the input variable, if requested. This module should be interactive and on-line for fast and suitable results. The information would be displayed in tabular, graphics and/or map forms. Suitability of the output to provide input to the other modules is also a requirement.

The COMMUNICATION module would provide the flood event communications, flood event operations and restoration part of the system. Early 'alert' to field agencies that an important storm is impending is important. After a forecast has been made for a flood or a drought, centres should inform the municipality or other appropriate agency of the imminent event and its implication. Flood monitoring and information exchange (which includes up-dating the model input) would be imperative. The notice of event termination is equally important.

The decision process would be initiated at this point. Both formal as well as automatic decisions could be supplied from the model to recipients of the warning (the decision makers) so that they can plan their responses (Krzysztofowicz and Davis 1984). These decision makers would be concerned about the degree of response, the type of protective

action to be taken, and the way of allocating resources to various protective activities.

The frequency of issuing a forecast would be important to consider. The timing may change based upon subsequent amendments or refinements, re-issue times, and emergency situations. Flood warnings are considered to be of value provided that they give sufficient time to evacuate people, animals, equipment and so on from a threatened area, time to prepare defenses to protect buildings and stationary equipment, and allow sufficient lead time to release water to provide for reservoir storage for flood water (Kite 1974). The particular combination of times and parameters to be forecast depends upon the user requirements.

The dissemination channels could be radio, TV, telephone, and various public and private organizations who, after receiving the forecast from the system/managers, disseminate the warning to potential users.

4.2 Information Requirements

The following real-time meteorological and hydrological information is required and available on-line: hourly air and dewpoint temperatures and precipitation every six hours (both rainfall and snowfall), hourly precipitation (tipping bucket data), daily net pan evaporation, hourly sunshine and radiation, hourly stream flow and water level data, hourly wind speed and direction, cloud opacity, cloud type and amount, 1 to 10 day prognostic charts, and the 50 kPa map in digital form. The precipitation data could be from both AES and non-AES ground networks and should include radar and satellite data, if possible.

Additional daily measurements are on-line, however, but are not available in real time. These include 15 minute and hourly rainfall

(Fischer Porter data), soil temperatures, and hourly wind runs, for examples. If they were made available online on a daily basis, modelling would be improved.

The hydrometeorological information required by water resource managers because of its use for the hydrological model(s) their agency is using can be reviewed using Table 4.2.1. All of these models in this table are currently used in Western and Northern Canada. The Streamflow Synthesis and Reservoir Regulation (SSARR) model and its derivatives are mainly used. All of these models are expensive and time consuming to set-up and calibrate, require large amounts of data for calibration, and are relatively expensive to operate.

In addition, the following historic information should be in an archive at the centre available on-line: long term records (>30 years) of hourly temperature, precipitation and winds, daily snowfall and snow cover, and hourly or daily sunshine and radiation. Other information needed include: extreme daily precipitation, storm analyses (need up-dating), 100 year persistent dew point temperatures (need up-dating), snow cover frequencies, list of significant storms (need up-dating), evaporation rates as a function of moisture, and runoff as a function of soil moisture.

Some additional information would make the hydrological models more efficient and perhaps more realistic. Examples of such information are: temporal statistical analysis of precipitation (e.g. what percentage of the total rainfall occurs in the first 24 hours of a 72 hour storm), effect of topography on prairie storms, soil moisture information, continued and better snow survey records, climate change effects on hydrology due to changes in precipitation and temperature, snow melt curves

Table 4.2.1 Watershed Model Comparison.

Model Name	Type	Operation	Approach	Time Period	Areal Scale	General Application	Availability
ANSWERS	Distributed	Discrete	Deterministic	Subhourly	40 mi ²	Agricultural	Public
BSAM	Lumped	Continuous	Deterministic	Monthly	Large	Irrigated Agricultural	Public
BURP2	Distributed	Continuous	Deterministic	Daily	Wide Range	Forested	Public
CREMS	Lumped	Continuous	Deterministic	Daily	40 acres	Agricultural	Public
HEC-1	Lumped	Discrete	Deterministic	Variable	Variable	Rural	Public
HSPF	Lumped	Continuous	Deterministic	Variable	Large	Rural and Urban	Public
PSRM	Distributed	Discrete	Deterministic	Variable	Urban Catchment	Urban	Public
PSU-IV	Transfer Function	Discrete	Deterministic	None	20 mi ²	Flood Flow	Public
Sacramento	Lumped	Continuous	Deterministic	Daily	60-1200 mi ²	Headwaters	Public
SCSTR20	Lumped	Discrete	Deterministic	Hourly	Variable	Rural	Public
SSARR	Lumped	Continuous	Deterministic	Daily	Large	Mountainous Terrain	Public
STORM	Lumped	Continuous	Deterministic	Hourly	Single Urban	Urban	Public
SWM	Distributed	Discrete	Deterministic	Subhourly	10-5400 acres	Primarily Urban	Public
TVA	Lumped	Continuous	Deterministic	Daily	Small to Intermediate	Rural and Urban	Public
USDAHL-74	Lumped	Continuous	Deterministic	Variable	Small	Agricultural	Public

Table 4.2.1 (Continued)

Model Name	Input Climate Data								Calibration	
	Precip.	Air Temp.	Dew Pt.	Radiation	Daylight Hrs.	Wind	Pan Ev.	Pressure		Albedo
ANSWERS	X									Yes
BSAM	X	X			X					Yes
BURP2	X	X	X	X	X	X		X	X	No
CREAMS	X	X		X						Yes
HEC-1	X	X	X	X		X				Yes
HSPF	X	X	X	X		X	X			Yes
PSRM	X									No
PSU-IV										No
Sacramento	X									Yes
SCSTR20	X									No
SSARR	X	X	X	X		X			X	Yes
STORM	X	X								Yes
SWM	X									No
TVA	X								X	Yes
USDAHL-74	X									Yes

Table 4.2.1 (Continued) Processes*

Model Name	Rain	Snow	Intercept	PET	Actual ET	Infil.	Soil Moisture (Zones)	Interflow	Baseflow	Overland	Channel	Deep Perc.
ANSWERS	+		+	-		0	0 (1)		-	+	+	-
BSAM	-	0		0		-		-	0			-
BURP2	0	0	0	+	0	0	0 (2)					+
CREAMS	0	0		+		+				0	0	+
HEC-1	0	0		-		-				0	+	
HSPF	0	+	0	-	0	0	0 (2)	0	0	0	0	0
PSRM	0		0	-		0				0	0	-
PSU-IV	-										0	
Sacramento	0			0		0	0 (2)	0	0	0		39 0
SCSIR20	0			0		0					0	
SSARR	+	+		-		-	0 (1)		0	0	0	0
STORM	0	0		-		-	-					
SWM	0			0		0				0	0	
TVA	-		0	-		-			-	-	-	
USDAHL-74	0	0	0	-	0	+	0 (1)		0	0	0	-

* + = more than adequately represented

- = rough approximation

0 = acceptable representation

blank indicates process not included

for all stations, snow melt versus temperature (2 per month), soil moisture curves, snow-line or percent of snow left in a basin, and the compilation of climate data as a function of basin (the method prior to 1976).

4.2.1 Water Resource Manager's Requirements

Before we discuss the detailed system, it is useful to look at the complexities involved in watershed modelling in relation to the types of information required by the hydrologists. This complexity is related to the multiple use of the watershed. The information required by watershed managers depends upon the particular set of issues involved (Table 4.2.2). This realization is indicative of the need for a multiplicity of watershed modelling capability. Hydrologists need models for such aspects as real-time reservoir control and dam-failure simulation as well as the standard channel routing and runoff-generating models.

In addition, hydrologists need to know the depression storage and active areas of a watershed, the pre-storm channel conditions, water uses in the basin, and the known and potential flood areas. This information should be available on-line.

A knowledge of the sensitivity of the watershed response to different storm types is necessary in order for the managers to respond correctly to each storm. Sensitivity analyses of each of the hydrological models that are being used operationally would also be useful in order to determine dominant parameters and possible sources of error. The 1979 Flood Forecasting Technical Workshop (Environment Canada 1979) recommended that Inland Waters Directorate, in concert with AES, should conduct such sensitivity analyses. The analysis would include the de-

Table 4.2.2 Hydrologic Issues and Associated Information Requirements.
(Source: James, Bowles and Hawkins 1982)

Hydrologic	Information Required
Flooding forecasting and control	Flood peaks Flood hydrographs Simultaneous flood hydrographs in regional streams Soil moisture conditions
Drought and low-flow river forecasting	Low river flows Timing of drought sequences
Streamflow regulation (irrigation)	Runoff volume Runoff time patterns Simultaneous runoff volumes in regional streams
Instream flow needs	
Fish and wildlife	Low river flows Within-year timing of low flows Timing of drought sequences Flow velocities
Recreation	Low river flows Timing of flow sequences Runoff time patterns
Navigation	Low river flows High river flows Formation of surface ice
Hydroelectric power production	Timing of flow sequences Runoff time patterns Simultaneous runoff volumes in regional streams

Source: Shafer and Skaggs (1983).

termination of the level of error in final predictions because of precipitation, temperature, snow cover and evaporation errors.

An increase in information, as provided by more detailed observation networks, that is integrated with radar and satellite data, and provided in real time could result in increases in forecast lead times. A study by (Baldrige et al. 1982) shows that an increase in forecast lead time provides a reduction in damage. The damage reduction in their study is applicable to action taken by individuals and not commercial businesses. This study showed that for flash floods, a 1 to 11% reduction in damage could be realized if the lead time was increased from $\frac{1}{2}$ to 4 hours. For a flood forecast (6 to 18 hours before the crest), a 12% decrease in damage could be realized if the lead time was increased from the present 4 hours to 14 hours. The above analysis could be used to justify better observational networks, and the implementation of radar and satellite technology.

4.3 The Needs of an Integrated System

Since an integrated forecast system should transform all data to a common geo-referenced data base, research is needed into appropriate methods for geo-referencing data. An interactive procedure is suggested to restructure the original data bank according to hydrological contributing areas. The majority of accuracy errors between satellite and ground data can be traced to geo-referencing errors. Further work needs to be done to correct these errors.

A model for daily forecasting of streamflow has to be run in a minimum of time with the available data. If data are not available from one source, pseudo data or another model input has to be inserted very

quickly. Ways are needed to implement this replacement procedure.

Further work is necessary to define expected errors and confidence limits in the output parameters. A coarse grid search can be used to optimize the broad area of minimum standard error followed by a search for local optimum or flow. The analysis would include the determination of the level of error in final predictions because of precipitation, temperature, snow cover and evaporation errors. Also it would allow one to assess where improvements need to be made to the forecast system. For example, it may help answer questions such as what combinations of better observational networks and radar and satellite technology would provide the best results?

The models should run on as many basins as possible, so they would be used not only on well-instrumented research basins but also on basins for which much less data is available. In the case of data-poor areas, the effects of deriving data from another source can be explored as mentioned previously.

5 DESIGN REQUIREMENTS OF THE SYSTEM

The flow chart (Figure 5.1.1) illustrates the flow of meteorological information in the Flood Forecast System. Once the data are received, they must be decoded, quality checked and put into a common data format and archived. Table 5.1.1 gives a brief summary of how the data would be handled, broken down by sources.

If the data indicate that some potential for flooding exists, then the forecasting team would begin to go through the flood forecasting mode, illustrated in Figure 5.1.2. A corresponding procedure would be used for drought and low flows. Otherwise the data handling is routine and the system would remain in research mode. Additional information on the meteorological forecasting methods and radar are given in Appendix E.

At the present time it is envisaged that an IBM-AT or a compatible computer would be used together with an IBM Professional Graphics Display Board, under a multi-tasking operating approach. The system would require two 1.2 Mbyte floppies, 80 Mbyte internal disk and 1.2 Mbyte RAM (random access memory). Because of the present regional weather office system, it is believed that the decentralized operation would be better suited for regional operations than if it were operated on a main frame computer. The system will have access to various types of data through the existing and future data transmission networks.

AES is presently improving its communications system (Kirk 1986). AES is implementing the Meteorological Satellite Information System (METSIS). This system will use satellite technology to disseminate meteorological information to some 70 locations across Canada. The traffic to be distributed will include: weather charts, satellite im-

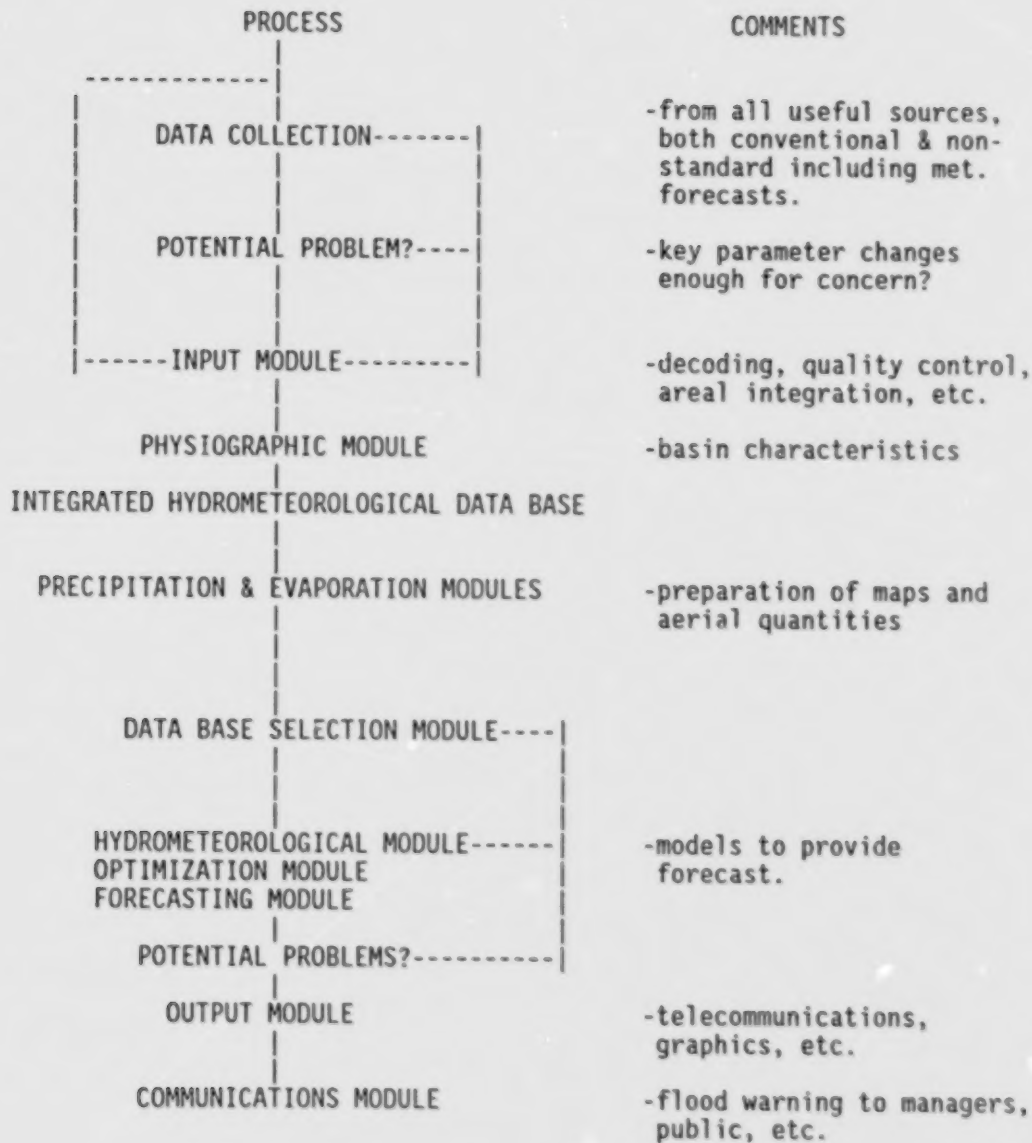


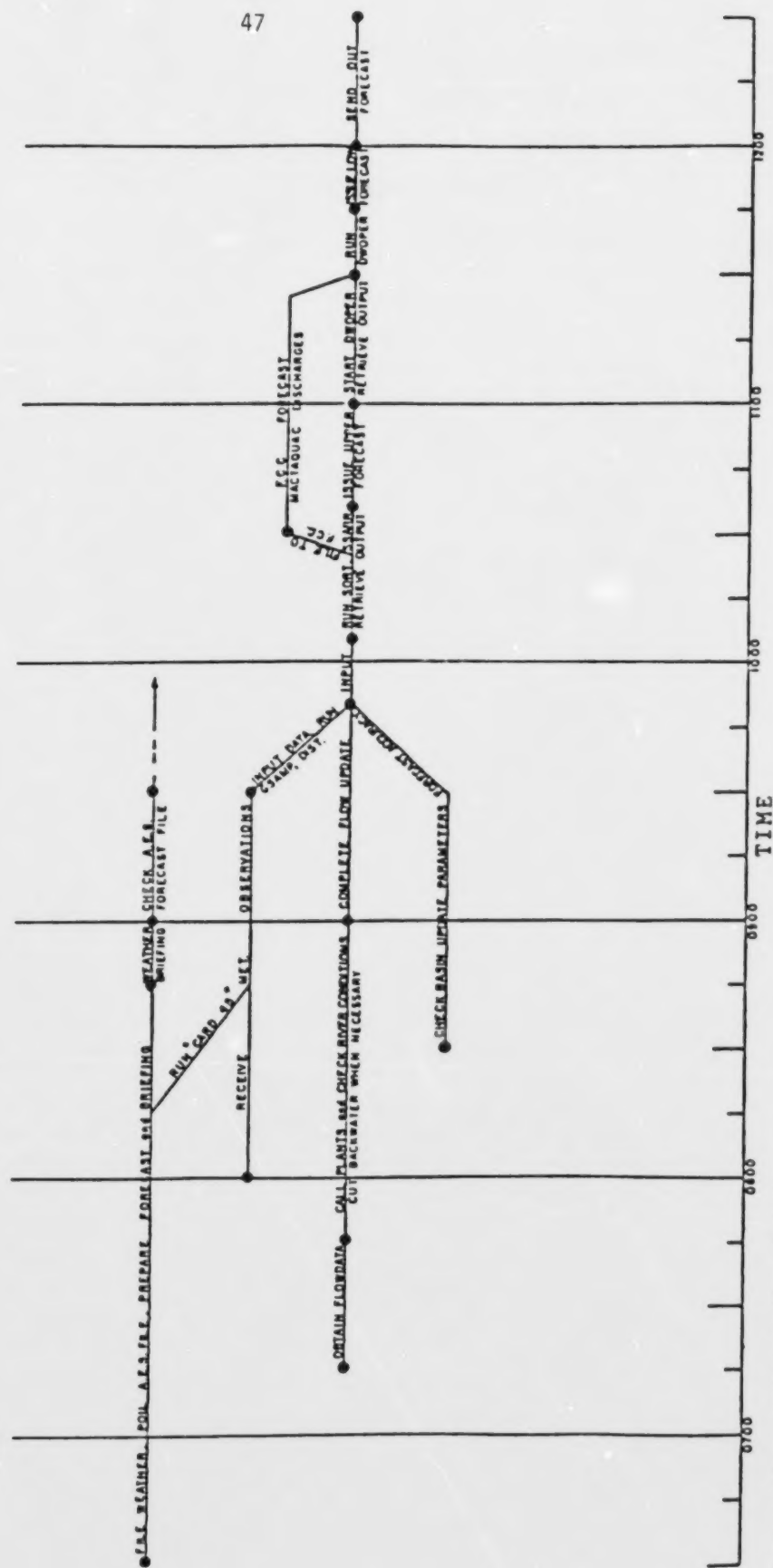
FIGURE 5.1.1 A HYDROMETEOROLOGICAL INFORMATION SYSTEM

note: ---- also indicates feedback loops

TABLE 5.1.1 DATA INPUTS TO THE MODEL

Source	Data characteristics
satellite: GOES	visible 0.55um - 0.75um red infra-red 10-12.5um thermal
radar: Enterprise	10 minute accumulations (Marshall-Palmer distributions) hourly accumulations re-mapped to GOES's scale
rain gauge data	hourly from climate stations and #1 stations.
quality control	probability of detection false alarm ratio critical success index field biases, mean standard error, correlation coefficients
AES teletype traffic:	
1. forecasts	- weather forecasts - outlooks - met. interpretations - QPF - LFM - severe weather - thunderstorm
2. observations	- hourlies - 6 hourly synoptics - 6 hourly precipitation
Digital radar maps	- CAPPI (pseudo) - accumulations
DCP and data loggers	
Archiving	- partially complete, disc to tape
Displaying data	

Figure 5.1.2 — CRITICAL PATH OPERATING SCHEDULE —
 ——— NORMAL-EMERGENCY —



Source: Tang and Lockhart (1985).

NOTE: CARD45 is the grid interpolation weather forecast program.

agery, radar, and alphanumeric weather forecasts. Within METSIS, satellite receiving stations will be installed at Weather Centres and Offices across Canada.

Also non-AES organizations can be included. These would be such as Ministry of Transport, Department of National Defense (DND), provincial governments and their crown corporations [hydro utilities] and private companies in the resource and transportation sectors). The Kirk (1986) study provides a data base of known current users, categories of users, technical options (including cost), and the technical impact of the changeover. This study found that only 3% of the present users require all the information that a flood/drought forecast centre would require. This would be a facility with one to four teletype circuits, facsimile, radar, and satellite imagery). There are ten of these facilities (DND has 5, and others have 5). There are no AES sites with this full complement of circuit information.

The recommended ground based communication distances for the amount of data necessary for the centre is 8 to 200 km (Kirk 1986). The satellite option is preferred for greater distances because of its economy. Once the earth station is installed there are no additional costs, and therefore the user can increase the amount of weather information received without increase in cost for communication. The cost for Telesat Canada ANIKOM 100 (probably the AES choice) is approximately \$351 per month. Where the flood/drought centre is not at an AES METSIS earth station a case by case study will have to be made. In general, a micro earth station for the delivery of teletype and facsimile, and terrestrial lines from the nearest METSIS earth station for the remaining information would be \$3,000 per month or alternatively, a dedicated digi-

tal line at 56 KBPS and a Satellite Packet Interface System (SPIS) unit would be \$5,000 per month. The maximum distance for private microwave is 30 km at \$1200 per month.

In the long-term, new models are probably required and should involve: up-dating general hydrologic land cover information, snow-covered areas for snow-melt-runoff algorithms, surface soil moisture from microwave data for water budget accounting and linkage to the soil profile, vegetation indices or biomass estimates, surface temperature for evapotranspiration, interception calculation, and high resolution data for channel networks and overland flow considerations (Rango 1985). Sophisticated Geographic Information Systems (GIS) are another possibility to enable rapid grid overlaying.

6 SUGGESTIONS FOR IMPLEMENTATION

The Pearse Board suggested that remote sensing, satellite communication and other advanced technologies should be explored to economize and improve information in water quantity [and quality] monitoring systems. The use of experience and expertise of AES was also suggested (Pearse et al. 1985). In order to accomplish the above-stated tasks, regional seminars and workshops for both meteorological and hydrological forecasters in hydrometeorology would help to open paths of communication. With aggressive training, forecasters can rapidly acquire skills in flood warning prediction (Belville et al. 1980).

CLI-GRID should be tested to determine whether it is the appropriate model to be implemented for Western and Northern Canada. For the first version of the system, a time step of 6 hours and a grid size of 5 km is recommended while later versions should use steps varying with hydrologic events with calibration by at least 25 rain gauges.

Remote transmission of information and hard-copy are necessary. METSIS is the recommended method to transmit the information among computer systems. For distribution of warnings to users, a system called STAR (Système Téléphonique d'Alerte aux Risque) from France is suggested to broadcast flood warnings over the regular telephone system (Obled 1986). The purpose of this system is to broadcast the flood warning to a pre-established list of addressees, according to the risk, its seriousness and area concerned. (Such systems can call 1000 numbers in 10 minutes.) The system will have to have some built-in redundancy or back-up. As the sophistication of users increases, their demands for accurate and more detailed real-time and historical information will increase.

This concept is not yet complete without a performance evaluation which must provide a logical and mathematical framework for analyzing the systems performance (Krzysztofowicz and Davis 1984).

6.1 An Implementation Plan

An improved method of integrating and delivering meteorological output to flood forecast centres is the suggested approach. Because water is a provincial responsibility under the constitution, the responsibility for water resource forecasting will continue to reside with the provinces. However, responsibility for flood forecasting is not well defined especially for interprovincial and international rivers. A joint federal-provincial committee is one approach to a coordinated development of a forecast system based on joint models. The Canada/Provincial Flood Damage Reduction Program is a mechanism to fund both the research and the implementation. Policies for the provision of this new service will be necessary. The responsibilities for all parties need to be defined.

In order to deal with the fast response of small watersheds and to lengthen warning times in larger watersheds with slower response, meteorological forecasts should be used. The flood reporting period of less than 6 hours requires the input of satellite and radar data. For forecasts longer than 12 hours, the fine scale detail is still required but it also requires the storm development and motion only available from complex numerical weather prediction models.

Maps of Quantitative Precipitation Forecast (QPF) for 12 hour periods up to 48 hours are available but flood forecasters require 120 hour forecasts which are presently available but not distributed. The Prob-

ability of Precipitation Amount (POPA) forecasts are produced twice per day for six consecutive 12 hour intervals for only 72 stations. For drought and some flood forecasts conditions the POPA forecasts need to be extended to 7 days.

The New Brunswick Flood Forecasting Centre Operations Manual (Tang 1981) is suggested as the prototype for the flood forecasting system operations manual.

6.2 Research Needs

6.2.1 Research Necessary For Implementation

The CLI-GRID project has taken an important first step towards defining the ability of satellites to estimate areal rainfall provided the time period is not less than 6 hours. Numerical weather forecasting for both the short and long term hydrological model input must be considered. The possibility of increasing the frequency of issuing the numerical weather forecast must, however, be investigated further. Since the QPF forecast estimates the occurrence correctly but under-forecasts the amount of heavy rain, the hydrological forecast is seriously affected. Therefore, further research must be considered to improve the QPF capability.

A system for daily forecasting of streamflow has to be run in a minimum of time with the available data. If data are not available from one source, pseudo data or another model input has to be inserted very quickly. For example, if 1.5 m mercury thermometer data at a particular station are unavailable, ways are needed to derive the temperature from the spatial distribution of net radiation and surface temperature from remote sensing.

Since the forecast system should transform all data to a common geo-referenced data base, research is needed into appropriate geographic information systems. An interactive procedure is suggested to restructure the original data bank according to hydrological contributing areas. Since the majority of accuracy errors between satellite and ground data are due to geo-referencing errors, further geo-referencing capabilities are required.

Further work is necessary to define expected errors and confidence limits. The analysis would include the determination of the level of error in final predictions because of precipitation, temperature, snow cover and evaporation errors. These routines could also be used to increase the speed of the system. For example, a coarse grid search can be used to optimize the system for minimum standard error followed by a search for local parameter maxima. These analyses could be used to justify better observational networks, and the implementation of radar and satellite technology.

The system should run on as many basins as possible - not only on well instrumented research basins. Appendix B lists operational and research basins in the west and north. The organization involved, data collected and problems or potentials of the basin and/or work are also listed. The Saskatchewan River is suggested as the test site for the flood and low flow forecasting system because of the calibration work already carried out (Prairie Provinces Water Board 1977) and excellent instrumentation in the basin and the current Federal/Provincial study (South Saskatchewan Study Board 1986).

The flood and low flow damage/loss estimates often ignore the cost of preparation, monitoring, forecasting the event and/or protecting

people and property. The flood and drought hazard illustrates a glaring, continuing social vulnerability to weather extremes. One useful step in an integrated hazard assessment and mitigation would be a more detailed and incisive meteorological risk analyses. For example, what are the relative roles of physical magnitude and social vulnerability in flood events? What is the proportion of avoidable versus unavoidable loss? How does this ratio change with changing perception of the flood, preparedness, and the quality of warning? The evaluation system should include the values, efficiencies and the expected opportunities for loss to capture the interplay between the performance of the forecast system and the performance of the response system.

In the long-term, new models are probably required and should involve: methods for up-dating general hydrologic land cover information, algorithms to determine for snow-melt-runoff relationships from snow-covered areas [better snow-melt models], surface soil moisture from microwave data for water budget accounting and linkage to the soil profile, vegetation indices or biomass estimates, more work on Rational method of storm analysis for the Prairies (e.g. storm rotation, adjustment factors), soil infiltration rates as a function of snow cover (percentage of basin), information on soil frost (runoff efficiency increases from 10 to 90% with increasing frost), surface temperatures for evapotranspiration, interception calculations, and high resolution data for channel networks and overland flow considerations.

It is recommended that any research be tied into international research projects already on-going or proposed such as International Satellite Cloud Climatology Project (ISCCP), International Satellite Land Surface Climatological Project (ISLSCP), Global Resource Informa-

tion Database (GRID).

6.2.2 Connecting The System To Economic and Socioeconomic Models

One useful outcome of the above mentioned integrated hazard assessment and mitigation system would be guidelines on the relative risks from different hydrometeorological hazards and on their impact across the socioeconomic sectors. The mere existence of a flood warning system has intrinsic human value even if never called upon to save lives or property. As the sophistication of users increases, their demands for more accurate and detailed real-time and historical information will increase. It is critical that meteorologists recognize hazard and emergency managers as key users.

6.3 Public Involvement

In order for the system to operate successfully, the public would have to be educated on the meaning of warnings and advisory statements. In order that the public credibility can be created, a prototype of the warning system must be verified with real-time data before being implemented. Although it is not the mandate of AES to develop flood response decisions procedures, AES can influence the degree of response, types of protective actions and the amounts of resources allocated by aiding preparedness planning (Barrett 1986).

Public involvement in the implementation of the system is required to provide support of the funding and because the public are the end users. Public involvement can flounder because of the lack of practical precedent in government circles. The situation can be compounded by reluctance on the part of some to accept a system with which they have

no experience or over which they have no direct control. Figure 6.3.1 shows an example of such a system.

Individuals will not heed flood warnings unless they personally feel at risk. In order to feel at risk, the individual must be made aware of the fact. Flood warning must contain specific information as to which roads, buildings, houses, etc., could be affected by flood warnings.

The optimal strategy is based upon the expected loss. The alternative is to base the strategy on human factors which are derived on the expected probability of loss. This method is suggested because field surveys indicate that people move into action only if warnings and losses are perceived to be quite certain. Expected loss is a better motivator than expected probability of loss. Also, early warnings tend to underestimate the crest of high floods, causing relatively low prior probability. This is consistent with observations that people do not readily evacuate the area on the basis of one warning. As a result, the human factor of strategy is less anticipatory and therefore less effective in coping with the forecast uncertainty and the decision constraints (Krzysztofowicz and Davis 1984).

Therefore, perhaps instead of investing solely in an organizational solution that would shorten the time needed to achieve maximum response, or waiting to implement a technological solution that would increase the forecast lead time, a more cost-effective alternative for the decision makers would be to also invest in behavioral solutions. This approach might be the development of an analytical model or artificial intelligent or expert system that would help to better use the forecasts and to make an optimal instead of a sub-optimal (heuristic) response

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GRAND RIVER CONSERVATION AUTHORITY
FLOOD WARNING MESSAGES - PROCEDURE

Step 1 - Duty Officer

Prepares draft message.

2 - Assistant General Manager,
 or General Manager, or
 Chairman

Approves message (If none
 available proceed to 3).

3 - Duty Officer proceeds

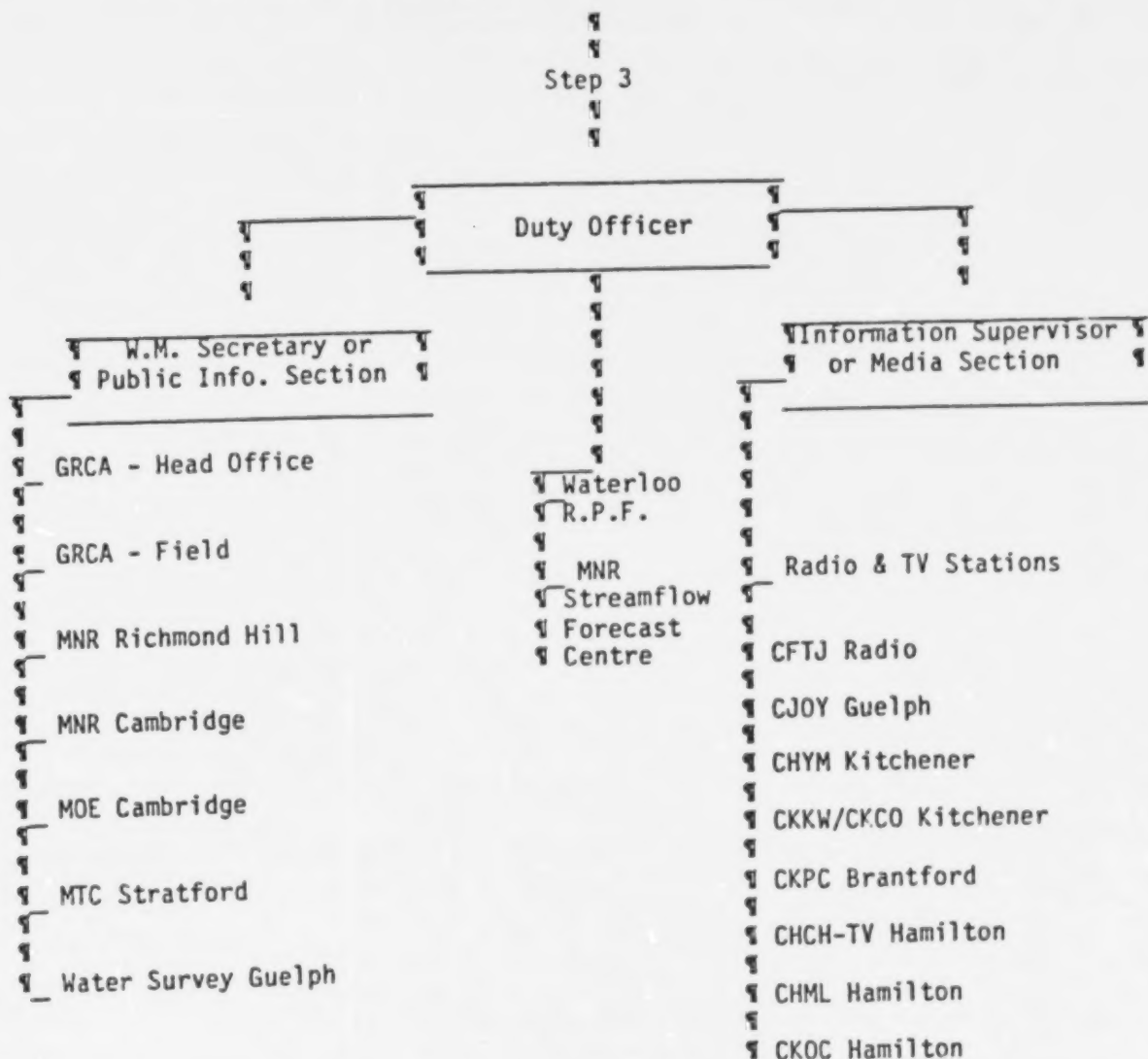


Figure 6.3.1

Source: Minshall (1985).

(Krzysztofowicz and Davis 1984).

6.4 Problems, Issues and Opportunities

The problems and issues often create opportunities for advancement. They include the following points:

- although automatic stations have several benefits, they have created some problems. Increases in the number and types of automatic stations create acquisition and data distribution problems. These stations also require standardization. There is a lack of snowfall and cloud type and cover data (especially in the winter) from automatic stations (Abraham 1987).
- priority conflicts between real-time users and operating agencies (e.g. requests for special forecasts) do arise. The study by Kirk (1986) showed that busiest time on the communications circuit is 2100-2159 hours GMT with 53 Mbits of traffic being delivered. If the flood/drought system requires 19 Kbit for each centre, will the system handle the data load?
- merging old data with new is a problem as the data are often gathered by two different sensor types, for example. This is especially difficult if comparison tests are not made.
- central versus regional data acquisition and dissemination is an issue.
- cost recovery and user pay policies make the initiation of the system difficult. The suggestion has been made that flood forecasting offices be set-up under the present flood reduction program. The federal government could set up the flood forecast centre and then turn it over to the provinces once it was operational (i.e. not in verification

or research mode).

- warnings and advisories are better than maintaining silence or withholding information due to uncertainty.

- longer (3-5) day forecasts have been transferred to the CRAY computer with emphasis placed on day one forecasting (Abraham 1987).

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APPENDICES

APPENDIX A
GENERAL STRUCTURE OF THE HYDROMETEOROLOGICAL DATA

The INPUT module: The objective of the INPUT module is on-line retrieval and quality control of conventional meteorological and hydrological data as well as less conventional data such as remote sensing data from satellites and meteorological radars. In addition, meteorological forecasts are also input (the early 'alert'). The INPUT module will next make that information available in suitable or proper format to the PRECIPITATION, EVAPOTRANSPIRATION, and OUTPUT modules. This module performs the data collection and management functions (including co-ordination). This module would also handle real-time up-dating (or initialization) to correct for errors in the earlier flood forecast. If data are not available from one source, pseudo data or input from another model could be utilized.

Accurate and timely data would be the basis of the whole system. Data archives would also be required. There would be also needed to feed other networks as well. The system needs to be easily accessible. Quality control procedures would be used to identify report errors. These error reports should include expected errors and confidence limits.

The PHYSIOGRAPHIC module: All variables related to basin characteristics, for instance terrain elevation, slope, and aspect, soils, drainage information and land-use would be modelled by this module. An off-line procedure first would prepare the data bank containing all pertinent information on the basin for later use in the system. A 5 x 5 km grid should be used initially, but the size could be changed. Land-use and soil data can be obtained and up-dated using remote sensing. An interactive procedure is suggested to restructure the original data bank according

to hydrological contributing areas.

The PRECIPITATION module: If radar data are available, this module prepares precipitation maps by calibrating with rain gauge data using information from the INPUT module on radar location and size of the radar pixel and the location and shape of the basin from the PHYSIOGRAPHIC module. The PRECIPITATION module includes a sub-module for snow accumulation and melt. This sub-module would be based upon the snowmelt index method at the present. Rainfall estimation from integrated satellites, radar and rain gauge data would use an adaptation of the CLI-GRID method.

The EVAPOTRANSPIRATION module: Actual and potential evapotranspiration would be obtained for each grid cell or contributing area through the use of various estimation methods depending upon availability of input variables. A method should be evaluated which uses remote sensing to derive the spatial distribution of net radiation and surface temperature. As a second choice the Penman type equation could be used to determine potential evapotranspiration from which actual evapotranspiration will be estimated using the soil moisture budget, as estimated from the HYDROLOGY module. Finally, if only air temperature and precipitation are available, a less accurate method, such as Thornthwaite, could be used.

The HYDROLOGY module: This module could be divided into two sub-modules: PRODUCTION and TRANSFER. The basin should be divided into contributing areas as determined by aggregating of grid cells as a function

of land-use, soil-type, topography, and drainage pattern. The production of water would therefore be derived for routing in streams. Water from contributing areas would be routed through a number of reaches in the drainage network by the TRANSFER function. Reservoir and lake routing are considered special cases of river routing.

The OPTIMIZATION module: Usually, distributed models are very complicated and use too much computer time so calibration of the model needs optimization to increase its speed. Multi-algorithms as suggested by Fortin (1985) would be based upon the Monte Carlo method which would be followed by conjugate gradient analysis. Another example of optimization is the hill-climb procedure described by Rosenbrock (1960). The best method, given the CLI-GRID model, is a coarse grid search to determine the broad area of minimum standard error followed by a search for local optimum or flow (Kik 1978). A sensitivity analysis should be done of the input parameters to find out which parameters have the most effect on flow simulation on an on-going basis.

The FORECAST module: The magnitude of the flood crest and arrival time at important sites would be calculated. The forecasting normally begins before the flood begins. Since no model is perfect and errors are also associated with streamflow measurements, up-dates with the latest information would be necessary. The target would be the same for both short-term and long-term forecasting. The possibility of up-dating the initial state of the variables should also be examined (Fortin 1985). The up-dates would be issued sequentially as new data were processed until the crest or low flow trend had passed.

The decision process would be initiated at this point: formal decision as well as automatic or un-aided decisions from the model by which recipients of the warning (the decision makers) plan their responses (Krzysztofowicz and Davis 1984). These decision makers would be concerned about the degree of response, the type of protective action to be taken, and the way of allocating resources to various protective activities.

The OUTPUT module: This module will display any requested result or input variable (such as radar). Remote transmission of information and hard-copy would be necessary. A model for daily forecasting of stream-flow would have to be run in a minimum of time with the available data. The model has to be developed so as to make maximum use of remote sensing data but it should also be able to run when remote sensing data is not available. The model should run on as many basins as possible - not only on well instrumented research basins.

This module would provide the flood event communications, flood event operations and restoration part of the system. Early 'alert' to field agencies that an important storm is impending is important. After a forecast has been made for a flood or a drought centres should inform the municipality or other appropriate agency of the imminent event and its implication. Flood monitoring and information exchange (which includes up-dating the model input) would be imperative. The notice of event termination is equally important.

The COMMUNICATION module: This module would provide the flood event communications, flood event operations and restoration part of the sys-

tem. Early 'alert' to field agencies than an important storm is impending is important. After a forecast has been made for a flood or a drought, centres should inform the municipality or other appropriate agency of the imminent event and its implication. Flood monitoring and information exchange (which includes up-dating the model input) would be imperative. The notice of event termination is equally important.

APPENDIX B
REFERENCES OF RESEARCH AND OPERATIONAL BASINS

Status of Basins - Operational

3, 23/87

Basin	Organization	Data Collected	Problems/ Potential
Carnation ck. watershed	Env.Canada, Cdn.For.Serv ice (1982)	rainfall, runoff, ground water levels, annual water yield (B.C.)	assess effects of road const. and forest harvesting on hydrologic regime
Carnation ck. Watershed	Env. Canada. Can.For.Serv ice.(1982)	Rainfall, runoff, ground water levels, annual water yield. (British Columbia)	assess effects of forest harvesting and road construction on hydrologic regime.
Chaplin L.	Sask.Env.(1981)	water, drainage basin, hydrology	
Chaplin L. Basin	Sask.Environment(1981)	water, drainage basin, hydrology	
Elbow R.(Alta.)	Alta.Res.Council(1982)	sediment, hydrology, hydromet stations, hydrographs	description of suspended sediment regime
Frenchman R. Notukeu ck	Sask.Environment (1981) (1983)	water, drainage basin hydrology	
Frenchman R., Notukeu ck.	Sask.Env.(1981)(1983)	water, drainage basin, hydrology	
Good Spirit L.	Envir.Canada Inland Waters(IHD study)	resources, hydrology, water balance, drainage	
Good Spirit L.	Envir.Canada Inland Waters(IHO study)	resources, hydrology, water balance, drainage	
Lee ck. watershed (Alta.)	Alta.Envir.(Hyd.Br.)(1983)	precipitation, measurements, a real value, VIM method, 2-axis method, snowpacks	methodology for translating out of basin, point precipitation

Basin	Organization	Data Collected	Problems/ Potential
Lee ck. watershed(Alta.)	Alta.Env.(Hyd.Br.)(1983)	precipitation, measurements, areal values, VIM method, 2-axis method, snowpacks	methodology for translating out of basin, point precipitation
Marmot and Tri ck. (Alta.)	see 81/RNRE 780009		
Notukeu ck.(Sask.)	see 46/RNRE 850147	Sask.Env.(1981)	
Notukeu ck.(Sask.)	Sask.Env.(1981)	See 46/RNRE 850147	
Peyto Glacier(Alta.)	Env.Canada Inland Waters(1979)	forecast models, discharge, prediction, snowmelt, runoff	model simulated discharge; comparison of models and algorithms. Predicted discharge compared to measured discharges
S.Sask.R., N.Sask.R., Sask.R., Qu'Appelle R. & Churchill R.	Water survey of Canada PPWB	stream flow forecasting, water supplement management, river flow	discussion of data transmission, forecast centres, forecast types and research needs
S.Sask.R., N.Sask.R., Sask.R., Qu'Appelle R., Churchill R.	Water Survey of Canada (PWB)	streamflow forecasting, water supply and management, river flow	discussion of data transmission, forecast centres, forecast types and research needs
Selected reservoirs in Alberta	Alta.Env.Hydro.Br.(1983)	inflow hydrographs, reservoirs, flood hydrology, flood forecasting	
Selected reservoirs in Alberta	Alta.Env.Hydro.Br.(1983)	inflow hydrographs, reservoirs, flood hydrology, flood forecasting	
Semans Sk.	Ag.Canada PFRA	rainfall, streamflow monitoring, reservoirs, storm runoff	assess rainfall-runoff response in small prairie watersheds

Basin	Organization	Data Collected	Problems/Potential
Semans, sk.	Ag.Canada P. F.R.A.	rainfall, streamflow monitoring, reservoirs, storm runoff	assess rainfall, runoff response in small prairie watersheds
Small watershed s in N.Central Alta.	see 43/RNRE 860013		
Souris Basin	Canada Dept. of Forestry (Oct./65)	hydrology, instrumentation, meteorology, hydrologic budget approach	improving land management for water yield, aquifer yield capabilities
Souris R.basin	Canada Dept. of Forestry (Oct/65)	hydrology, instrumentation, meteorology, hydrologic budget approach	improving land management for water yield, aquifer yield capabilities
Wiwa ck and Wood River (Sask.)	Dept.of Environment Sask (1981)	water, hydrology	
Wiwa ck. and Wood R.(Sask.)	Dept.of Env. Sask.(1981)	water, hydrology	
Yukon R.	Envir.Canada, Inland Waters	hydrologic flow model, hydrologic data, discharge, streamflow, flow control, reservoirs, SIMPAK program	hydrologic flow routing models
Yukon River	Envir.Canada, Inland Waters	hydrologic flow model, hydrologic data, discharge, streamflow, flow control, reservoirs, SIMPAK program	hydrologic flow routing models
Yukon Territory	Canada, Ind. and North. Affairs(1980)	climatology, hydrology, precipitation, snowpacks, snow surveys	bi-monthly publ. describing snowpack conditions, weather, stream flow conditions

Status of Basins - Operational?

3/23/87

Basin	Organization	Data Collected	Problems/ Potential
Alberta R.	Alta.Env.(Hydrology Br.) (1980)	precipitation, lit. review, storms, climatology, statistical rainfall dist., max. prob.precip.snowmelt	estimate of max. probable precip.
Alberta river basins	Alta.Env.(Hydrology Br.) (1980)	precipitation, lit. review, storms, climatology, statistical rainfall dist., max. prob.precip. snowmelt	estimate of maximum probable precipitation
Alkali ck., Bull pound ck., Monitor ck.	Alta.Env.Hydrology Br.(1979)	streamflow, synthetic hyd.	15 yrs. of data from 3 gauged stations
Antler R.(Sask-Man)	PFRA, Hyd.Div.(1978)	natural flow, hydrometry, gauging stations, reservoirs, hydrologic data, regression analysis	
Battle R.	Alta.Environment(1983)	natural resources hydrology, water demand, reservoirs, feasibility	
Battle R.	Alta. Environment (1983)	natural resources hydrology, water demand, reservoirs, feasibility	
Carnation ck. watershed	Env. Canada. Can. For. Service (1982)	Annual water flow, slope and valley char., storm hydro-graph peak and low flows (British Columbia)	estimative, storm runoff impacts in areas of clear cutting forest operations
Carnation ck. watershed	Envir. Canada, Cdn.For.Service.(1982)	annual water flow, slope and valley char., storm hydro-graph peak and low flows (B.C.)	estimates, storm runoff impacts in areas of clear cutting forest operations

Basin	Organization	Data Collected	Problems/Potential
Crane L. (Sask.)	Sask. Env. (1984)	geology, water supply	study of apportionment agreement of 1969
Crane L. Basin (Sask.)	Sask. Environment (1984)	geology, water supply	
Elbow R. (Alta.)	Alta. Res. Council	geog., flooding, control and flood forecasting	
Elbow R. Basin (Alta.)	Alta. Res. Council	geog., flooding, control and flood forecasting	
Eyehill ck. (Alta.-Sask. border)	Env. Canada, Inland Waters (1982)	streamflow, water use, catchment areas, hydrology, stat. and regression analysis	
Firebag R. (Alta.)	Alta. Res. Council (1982)	geology, hydrology, meteorology, hydromet.	
Firebag R. Basin (Alta.)	Alta. Res. Council	geology, hydrology, meteorology, hydromet.	
Frenchman R. (Sask.)	Sask. Environment (1983)	geog., hydrology	climate data and use by hydrology section, Northern For. Res. Center
Frenchman R. (Sask.)	Sask. Env. (1983)	geog., hydrology	
James R., Marmot ck. & Streeter ck.	North For. Res. Center, Fish and Env. Canada (1977)	data collection, climate, snow accum., snowmelt, met. data, snowpack, forestry, evap. rain	
Lee ck. (Alta.)	Alta. Env. Hyd. Br. (1982)	snowpack, snow pillows, met. data collection, lysimeters, hydro thermographs, forest watershed	
Mackenzie Delta (NWT)	Env. Canada, Glaciology Div.	hydro. data, hydraulics, discharge, ice, floods, ice-water interfaces	
			hydromet network to determine discharge and seasonal distribution of flows

Basin	Organization	Data Collected	Problems/Potential
Mackenzie R.	AES, Inland Waters Dir.	Env.Studies, hydrology, meteorology, precip., climate change, hydromet, temp.	compilation of drainage area data used in studies
Mackenzie R.(Sask.)	Sask.Env.	drainage basin info. hydrologic data	
Mackenzie R.Basin	AES Inland Waters Dir.	env.studies, hydrology, meteorology, precip. climate change, hydromet., temp.	
Magpie R.(N.Ont.)	Env.Canada, Network Planning Forecasting Section	weather forecasting, hydrologic models, National Weather Service River Forecast system, Sask. R. model, flood forecasting, streamflow synthesis and reservoir regulation	3 hydrologic models calibrated and verified on watershed in Ont., smaller, simpler model designed and tested
Milk R. (Alta.)	P.F.R.A. (1978)	environment, water, reservoirs	June 1964 flooding due to peak discharges in streams of Montana and S.W.Alta.
Milk R.(Alta.)	P.F.R.A.	environmental, water, reservoirs	
Milk R.(Alta.)	Alta. Env.(1980)	env.studies, land use capabilities, reservoirs, dams	
Milk River (Alta.)	Alta.Environment (1980)	env.studies, land use capabilities, reservoirs, dams	
Oldman R,Milk R.(Alta.)	Env.Canada Inland Water Dir.	floods, peak flows, meteorology, flood damage, frequency, precip., diversions	
Oldman R.(Alta.)	Thompson, Bercha, and Assoc.(1979)	water balance model, hydro-simulation, hydro.data, reservoirs, return flows, water supply	Oldman water balance model used to evaluate structural alternatives to improve water supply

Basin	Organization	Data Collected	Problems/Potential
Peyto Glacier	see 63 RE E83(00):059729 & 63 RE E83(00):059726	1982	
Peyto Glacier(Alta.)	Env.Canada(1976)	hydrologic data, meteorological data collection, discharge, snowmelt, runoff	features of discharge record 1967-74 from hydro., meteorological, & glaciological data collected
Peyto Glacier(Alta.)	Env.Canada, Inland Waters(1978)	streamflow forecasting, estimating equations	
Pincher ck. (Alta.)	Alta.Env.(River Eng.Br.)(1980)	flood plain delineation, hydrometric data, flooding, flood frequency, models	model used to compute water surface profiles for 100 yr. and 50 yr. events.
Pincher ck.(Alta.)	Alta.Env.(River Eng.Br.)(1980)	flood plain delineation, hydrometric data, flooding, flood frequency, models	model used to compute water surface profiles for 100 yr. & 50 yr. events
Pine Lake (Alta.)	Alta. Res. Council(1982)	Sask.Env.(1981)	geog., hydrology, water resources, groundwater
Pine Lake Basin (Alta.)	Alta.Res.Council (1982)	geog., hydrology, water resources, groundwater	
Prairies	Keith Consulting(1978)	streamflow, peak discharge, runoff, frequency analysis, forecasting and hydrological design	
Rocky Mts. area (Alta.)	Agriculture Canada(1961)	streamflow, gauges, monitoring, hydrology, networks, climate runoff	determine reliability of small watershed research to climate and runoff in area

Basin	Organization	Data Collected	Problems/ Potential
Saqvaqujac project(NWT)	Dept.Fish & Oceans Canada(1981)	hydrology, climate data, meteorology, climatology	1977-80 collection of hydromet data in support of biological and limnological studies
Sask.	Sask.Res.Council(1975)	hydrology, evap., reservoirs, hydrometeorology, soils, topo., climate, groundwater	evaporation from prairie sloughs, reservoirs and lakes
Selected streams in Mackenzie R.(Alta.)	Env.Canada, Water Survey of Canada	hydrology, ice break up, streamflow, discharge	
Seymour R., Jamieson ck.(B.C.)	Dept.Soil Science, U of Alta.(1983)	model studies, hydrographs, interflow, storms, precip., hydrologic models	sluices model dev. for simulation of interflow on forested, mountainous watersheds
Sheep River(Okotoks,Alta.)	Alta.Env., River Eng.Br.(1981)	flooding, hydrology, gaging stations, water level fluct. flood frequency, computer models	areal delineation of 1:100 yr. flood, and water surface profiles for 1:100, 1:50, 1:20 yr. events
Small basins in N.Central Alta.	Alta.Res.Council(1985)	geology, drainage basins, runoff, water flow, surface water flow	
Small basins in North Central Alta.	Alta.Res.Council	geology drainage basins, runoff, water flow, surface water flow	
Small watersheds in N.Central Alta.	see 43/RNRE 860013		
Spring ck.(Alta.)	Assoc.Eng.Serv.Ltd.(1982)	hyd.models, Hymo evaluation, rainfall-runoff relation, hydrographic analysis, parametric hydrology	

Basin	Organization	Data Collected	Problems/ Potential
watershed on west coast of B.C.	B.C. Water Resources Hyd. Div.	streamflow, logging, peak flows, soil channels, soil infiltration, hydrology	initial changes in peak flow following logging of a watershed
Watson L. (Yukon)	Civ. Eng. U of Alta. (1974)	hydrology, erosion watershed mgmt., channel erosion	
Wilson ck. (Man.)	Manitoba Natural Res. and Freshwater Institute	streams, hydrology, flooding, runoff, flows, groundwater, erosion, land use	
Wilson ck. (Man.)	Manitoba Natural Res. and Freshwater Institute	streams, hydrology, flooding, runoff, flows, groundwater, erosion, land use	
Yukon R.	Yukon R. Basin Committee / Dept. Ind. Affairs	hydromet data, data collection networks, hydromet station, meteorological data collection, snow course	assessing adequacy of data collection networks
Yukon River	Yukon R. Basin Committee, Dept. Ind. Affairs	hydromet data, data collection networks, hydromet station, meteorological data collection, snow course	assessing adequacy of data collection networks

Status of Basins - Research

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Basin	Organization	Data Collected	Problems/Potential
Baptiste L. (Alta.)	Dept. Geol. U of Alta.	model studies, groundwater hydrogeology, water quality, precipitation, evap. forecasting	simulate 6 yr. history of lake level fluctuations
Alberta oil sands	Oil Sands Env. Res. Program	geology, drainage basins, delineation	
Alberta oil sands	Oil Sands Environmental Research Program	geology, drainage basins, delineation	
Alpine Basin (B.C.)	Geog. Dept. McMaster Univ.	alpine basin, streamflow, snowmelt, ablation, meteorology, runoff, glaciology	alpine streamflow to variable snowpack thickness and extent
Alta. watershed Sask. R.	Env. Canada, North. For. Res. Centre.	streamflow, quality, hydrology, snow distribution accumulation patterns, erosion, wind pattern	Alberta watershed research program - mgmt. of headwaters to enhance water yield, regime and quality
Athabasca R. (F. MacMurray to Embarras)	Alta. Res. Council (1977)	hydrologic aspects, flow rates, ice jams, water levels	
Athabasca, Smoky & Peace R.	Dept. Eng. U of Man. (1974)	diversion, streamflow, hydrology, streamflow, cost benefit, water needs, demand, supply	
Bad Lake watershed	U of S, Div. of Hyd. (1977)	rainfall, forecasting, intensity, spatial distribution, variability, storms, gauges	spatial characteristics of prairie rainfall - 1968-75; low intensity, small rainfall events

Basin	Organization	Data Collected	Problems/ Potential
Baker ck.(NWT)	Dept.Geog.U of Alta.(1969)	Thorntwaite water balance, hydro.cycle, climate, snow, basin studies, evap.trans.	invest. aspects of hydrol. cycle
Baker ck.(NWT)	U of Alta.(1973)	evaporation - evapo-transp. water balance, precip., hydrology, energy budget, climatology	define average annual patterns of evaporation and evapo-transpiration for surfaces in the Baker ck. basin
Battle R.	Alta.Dept.of Env.(1980)	engineering, hydrology, hydrogeology	
Battle R.(Alta.)	Civil Eng. UofS(Dec/80)	streamflow, water util., monitoring, stats., precip., runoff, hydro aspects	analysis of streamflow records
Battle R.basin	Alta.Dept. of Env.(1980)	engineering, hydrology, hydrogeology	
Beaver Lodge R., Beaver Tail ck., Steeprock ck.	Alta. Env.(1977)	hydrology, erosion meanders, land use watersheds, bank protection	
Beaverlodge R.(Alta.)	Alta.Env.(1978)	water resources, existing data and literature review	
Boot ck. and Peter Lake	see 180 E79(A):035135		
Boot ck., Peter ck.(NWT)	Env.Glaciology Div.(1974)	hydro. data pipeline s, water supply	assessment of pipeline and hwy. designs
Boreal Forest(Alta.), Spring ck.	Alta.Env.(1980)	model studies, runoff, regression analyses, hydrologic data	evaluation in changes in snowmelt runoff volumes induced by basin manipulation

Basin	Organization	Data Collected	Problems/Potential
Bow-Valley (Alta.)	Geog. Dept., U of Calgary (1966)	floods, hydrology, geog. landscape, vegetation, meteorology, precip.	studies of changes in landscape of the Bow Valley (Alta.)
Bridge R. (B.C.)	Dept. Geog. U of B.C. (1979)	water balance, snow hydrology, snowmelt, measurements, alpine watersheds	energy and water balance studies in a small alpine watershed
Canadian coast watershed	U of B.C. (1972)	forest hydrology and soils, water balance, precip., evap., statistical methods	describe process controlling amount of water absorbed by forest floor
Carnation ck. (B.C., Vancouver Isl.)	Env. Canada, Fish and Marine Service (1976)	watershed mgmt., forest industry, streams, slope hydrology, water chemistry, stream algae, sediment transport	integrated resource mgmt. guidelines for coastal forest, stream ecosystem
Carrot R. (Sask.)	Dept. Northern Aff. & Nat. Resources (1965)	flooding, precip, runoff, meteorology, damage	flood of 1957 in Carrot River basin
Chick L.	B.C. Hydro and Power (1979)	precip., runoff, data collection, models, flood flows, CLARK model	estimation of small basin flood flows in discontinuous permafrost zone
Churchill R. (Sask.), Reindeer R.	Sask. Env.	river basin dev., hydro-electric pot., hydrologic data, environment, stream flow, cost benefit	synthesis of the Churchill Study sectors
Coast Mountains (B.C.)	Geog. Dept., U of B.C. (1975)	hydrology, altitude, continentality, precip., discharge, environment solute load	comparison of hydrologic inputs, throughputs and outputs based on elevation, range and continentality

Basin	Organization	Data Collected	Problems/Potential
Cold Lake - Beaver R.	Alta.Envir.(1983)	geology, groundwater mod.res.allocation	baseline hydrological and morphological info. on rivers stream flow routing models, SIMPAK for river modelling
Cold Lake, Beaver R. basin	Alta.Environment (1983)	geology, groundwater modelling, resource allocation	
Cree L.	PFRA, Hydrology Div.(1970)	hydrology, water levels, diversion, flow rates	
Firth R. and Babine R.(Yukon)	Northern Eng.Serv./Dept. Ind.Aff. & North Dev.(1976)	hydrology, channel morphology, hydraulics, watershed	
Fraser R., Columbia R., Mackenzie R.	Inland Water Dir.(1979)	SSAR, SIMAK program, stream flow, flood forecasting, hydro. data flood control	
Glacial L. Agassiz	Geol. Survey of Canada(1983)	geology, Lake Agassiz, hydrology, drainage basins	
Glacial L. Agassiz	Geol.Survey of Canada(1983)	geology, Lake Agassiz, hydrology, drainage basins	
Good Spirit L.	Env.Canada, Hydrology Div.(1978)	streamflow, model studies, simulation analysis, runoff, snow melt, hydrology, water balance	
High Arctic	Nat.Science and Res.Council/Inland Water Dir.(1983)	snowmelt, runoff, snow cover, radiation, floods, lit.review	
Hinton-Edson area(Alta.)	Fish & Env.Canada(1972-75)	hydromet, precip., stream discharge, soils, vegetation, geology	

Basin	Organization	Data Collected	Problems/Potential
Hodgson ck.	F.F.Slaney Co.(1973)	planning, bridges, Mackenzie Hwy., env. effects, hydrology	basic env. data
James R., Oldman R., Marmot R., Streeter R.	U of B.C. (1980)	streamflow, snowpack, evap., soil water, snow accum.ablation	
Jamieson ck.	Min. of Env. B.C.(1972)	rainfall, snowmelt, storm flow, hydrology, recession characteristics, rainfall-storm flow relationships	analysis of 4/storm hydrographs to evaluate storm flow characteristics in Jamieson ck. watershed
L.Athabasca, Churchill R.	Sask.Water Resources Commission(1971)	diversion, reservoir yield, structures, dams	
L.Winnipeg(Man.)	Dept.Fish and Oceans(1980)	hydrology, limnology, agric., runoff, chemicals, fertilizers, mixing, sediments	
Lake Athabasca	Mackenzie R. Basin Study report (1981)	sand dunes, hydrology, meteorology, runoff, waterflows, climatology, shoreline erosion (Sask.)	
Lake Athabasca	Mackenzie R. Basin study report(1981)	sand dunes, hydrology, meteorology, runoff, waterflows, climatology, shoreline erosion(Sask)	
Lake of the Woods(Man.)	Env.Canada, Inland Waters Dir.(1982)	hydrologic models, math models, conceptual models, forecasting, stat. and prob. models, flood damage	
Lee ck. Alta.	Alta. Environment (1984)	soil moisture data, precip. sampling, vegetation, water consumption by plants	

Basin	Organization	Data Collected	Problems/Potential
Little Smith ck (NWT)	F.F.Slaney Co.(1973)	planning, hydrology, env. effects, soils, fisheries	basic env. data
Mackenzie	Gregory Geos cience Ltd.	satellites, snow cov er, snow melt, runof f, hydrology, temp. and precip.	use of satellite images to map sno w cover and monit or peak runoff
Mackenzie Plain	Ag.Canada(19 75)	meteorology, agricul ture, degree days, insolation, precip., wind, evap.	climate of the Ma ckenzie Plain
Mackenzie R, St . Elias Mts.	Physics Dept , U of Alta (1972)	ice, snow conditions , isotopic physics, meteorology, snow wa ter equivalent	correlating isoto pic variations wi th meteorological trends
Mackenzie R.	Env.Canada, Glaciology Div.	ice breakups, jams, navigation, hydro.da ta, aerial photo, er osion	monitor channel ice effects and surface water vel ocities
Mackenzie R.	Dept.Geog., U of B.C.	water balance, perma frost, hydrology, ru noff, thermal proper ties	summary info on water balance in North America
Mackenzie R.	see 74 RE E8 2(00):059374		
Mackenzie R.	Env.Canada(1 974)	hydro.studies, groun d ice, precip., runo ff, erosion and wate r supply	
Mackenzie R.	U of Man.(19 74)	permafrost, hydrolog y, runoff, precip., ice	
Mackenzie R.	Govt.of NWT(1979)	water mgmt., downstr eam crises, hyd. sys tem, alluvial ecosys tems, spring floods	
Mackenzie R.	see 74 RE E8 2(00):059374		
Mackenzie R.	see 80 E82(0 0):058378		

Basin	Organization	Data Collected	Problems/Potential
Mackenzie R.	Bolter, Parish, Trimble Consult.Eng. (1974)	permafrost, hydrology, runoff, drainage, engineering	
Mackenzie R.	Env.Canada(1972)	hydrology, nat.resou rces, climate, vegetation, soils runoff	
Mackenzie R.	see previous entries		
Mackenzie R.	see 74 RE E8 2(00):059374		
Mackenzie R.	see previous entry		
Mackenzie R.	see previous entry		
Mackenzie R.	Env.Canada(1974)	rainfall, meteorology, forecasting, monitoring	forecasting of significant rainfall amounts.
Mackenzie R.	Imp.Oil, Gulf, Shell(1974)	climate, hydrology, environmental aspects	environmental impact assessment
Mackenzie R.	Env.Canada, Inland Waters Dir.	hydrology, streamflow, precip., snowmelt, design flow, sediment loading	measurements at 5 study sites along Liard Hwy.
Mackenzie R.	article for Canadian Water Resources Journal(1980)	geog., water resources, water management, flooding, flood plains	
Mackenzie r.(At habasca & Clear Water R.)	Alta.Mun.Affairs	flooding, control, forecasting, and flood freq.	Fort MacMurray flood damage abatement tech.committee
Mackenzie R.(NW T)	Acres Consulting Services	streamflow, climate, floods, hydrology, water yield, geology, vegetation	compile/analyze existing data, identify data deficiencies

Basin	Organization	Data Collected	Problems/Potential
Mackenzie R. (NW T)	Env. Canada, Inland Waters Dir.	flooding, water velocity, design, and design flows, stream crossings, peak discharges	
Mackenzie R. (Sask.)	Sask. Water Res. Commission	hydrologic data, hydro. met needs, surveys, networks	determine hydro - net requirements in Canada
Mackenzie R., Sask.-Nelson R. (drainage basins with Alta)	Alta. Env. (1978)	hydrologic data, drain. area, watersheds	determine contribution of drain areas to major river systems
Mackenzie R., Churchill r.	Sask.-Nelson Basin Board (1972)	hydrology, channel routing, env. impact, hydro. power	effects of diversion on env. of Mackenzie and Churchill R.
Mackenzie R. Yukon-NWT	Mackenzie River Basin Committee (1981)	review of previous network studies, hydrologic and snow course networks and met. networks	gaps in existing network and tentative suggestions for closing gaps
Mackenzie R., Columbia, Fraser, Coastal, Vancouver Is., Skeena, Nass, Stikine, Taku, Yukon, Liard & Peace	B.C. Energy Board (1972)	hydro-electric power, hydrologic data, stream flow, flooding design	hydrological analysis
Macleod R., Wampus ck., Deslik ck., Eunice ck. (Alta.)	Alta. Energy and Natural Res. (1978)	logging, biology, hydrology, climate, water quality, fish	test effectiveness of existing controls on logging operations
major river systems in Yukon	Sigma Res. Council (1975)	hydro power, hydrologic data, discharge, flow rates, flooding	
Manitoba	Can-Man. Flood Damage Red. Program (1978)	floods, flood forecasting risk, mapping, flood flow, hydrology	Annual report of Can-Man. Steering Committee on Flood Damage reduction

Basin	Organization	Data Collected	Problems/Potential
Marmot and Tri ck.(Alta.)	see previous Marmot and Tri ck. studies		
Marmot ck basin	Univ. of Alta. (1967)	geology, groundwater , groundwater exploration	provide essential data on headwater area
Marmot ck watershed	Forest Res.B r. Can.Dept. of Forestry	hydrology investigation, met.data, watershed mgmt.	
Marmot ck.	Univ. of Alta.(1967)	geology, groundwater , groundwater exploration	
Marmot ck. watershed	Canadian Forestry Service	snowpack, ablations, water balance	watershed mgmt. purposes
Marmot ck.(Alta.)	see previous studies		
Marmot ck., Cabin ck.(Alta.)	U of B.C.	streamflow, calibrations, methodology, analysis, hydrology	calibration methods for detecting streamflow changes
Marmot ck.watershed	Forest Res.B r., Cdn.Dept. of Forestry	hydrology investigation, met.data, watershed management	provide essential data on headwater area
Marmot ck.watershed	Canadian Forestry Service	snowpack, ablations, water balance	watershed mgmt.purposes
Marmot watershed(Alta.)	Northern Forest Res.Center(1982)	snow mgmt, stream flow- hyd.budget, snow accumulation, snowmelt, clear cutting ablation	
McKenzie R.Basin	article for Canadian Water Resources Journal (1980)	geog., water resources, water management , flooding, flood plains	

Basin	Organization	Data Collected	Problems/Potential
McKenzie, Kazan, Dubawnt, Thelon, Hanbury rivers	U of Western Ont. and Waterloo Univ. (1975)	biophysical impacts, env. effects, hydro. power, hydrology, surface and ground water, permafrost	biophysical impacts of Arctic hydro-electric developments
McMaster R. (NWT)	Geog. Dept. McMaster Univ. (1983)	hydrology, snowmelt, streamflow, runoff, rainfall	est. seasonal and annual water balances
McMaster R. (NWT)	Geog. Dept., McMaster Univ. (1983)	hydrology, snowmelt, streamflow, runoff, rainfall	est. seasonal and annual water balances
Mountain streams, Prairie streams	U of S (1977)	flood frequency, hydro. conditions snowmelt, flood analysis, Moldav Flood Analysis, long term data accuracy	applicability to various statistical dist. to flood frequency distribution
Muskeg R (Alta.)	Alta. Env. (1979)	met. char., streamflow, precip. patterns, pot. evap., and evap. trans., flows, sediment yield	
Muskeg R.	see 80 E82(00):058378		
Muskeg R. (Alta.)	Alta. Environ. (1979)	met. char., streamflow, patterns, pot. evap., and evap. trans., flows, sediment yield	
Muskeg R. (Alta.)	Alta. Res. Council (1982)	geol., hydrology, sediment, vegetation	vegetation removal and its effects on hydrolog. and sediment regimes of Muskeg R.
Muskeg R. (Alta.)	Dept. Geology U of Alta.	water quality, hydro. cycle, stream flow, surface water, models, surface - ground water relationships	

Basin	Organization	Data Collected	Problems/Potential
Muskeg R. (Alta.)	Alta. Res. Council (1982)	geol., hydrology, sediment, vegetation	vegetation removal and its effect on hydrologic and sediment regimes of Muskeg R.
Muskeg R. (Alta.)	see 57/RNRE 840078		
Muskeg River (Alta.)	see 57/RNRE 840078		
N. Bruns. N. Scotia, Nfld., various basins	Env. Canada, Water Res. Branch, Inland Waters Div. (June/80)	met. data, hydrological data	evaluate quality and quantity of hydro. met. data available; support future related research
N. Brunswick, N.S. and Nfld.; various basins	Env. Canada Water Res. Branch Inland Waters Dir. (June/80)	met. data, hydrologic budget approach	evaluate quality and quantity of hydro. met. data available - support future related research
N. Sask. R.	Northwest Hydraulic Cons.	surface water, water quality, sewage effluent	
Nicomex/Serpentine (B.C.)	Env. Canada, Inland Waters (1978)	hydrology, geology, ground water, stream flow, glacio-marine environment, water chemistry, irrigation	
Nigel ck. (Alta.)	Geog. Dept. U of Sheffield, Eng.	channel geometry, stream adjustment, sediment transport, hydrology, gauging stations	stream adjustments to environmental constraints
Nipawin Prov. Park (Sask.)	Nat. Res. Council (1982)	piezometer, water table, precip. temp.	
Ochre R.	F.F. Slaney Co. (1983)	planning, bridges, Mackenzie Hwy., env. effects, hydrology	basic env. data

Basin	Organization	Data Collected	Problems/Potential
Okanagan	Can-B.C. Okanagan Basin Agreement(1974)	water quantity, hydro geology, geography, hydrology, meteorology	water quantity studies
Oldman R.(Alta.)	Acres Consulting(1978)	water supply, resource development, math - models, simulation, hydrology apportionment	water balance model
Oldman R. (Alta.)	Grad. student, Brigham Univ. USA	hydrology, irrigation	
Oldman R. (Alta.)	Alta.Envir.	hydromet stations, network, streamflow, hyd.data, stat.analysis of adequacy of network	demand for hyd.data
Oldman R.(Alta.)	North West Hydraul.Consul.(1980)	forest mgmt, improved water yields, irrigation, hyd.data, clear cutting	
Oldman R.(Alta.)	Grad. student, Brigham Univ. USA(1970)	hydrology, irrigation	
Oldman R.(Alta.)	Alta.Env.(1981)	hydromet stations, network, streamflow, hyd.data, stat.analysis of adequacy of network	demand for hyd.data
Ooblayah Valley, Ellesmere Is.	see RE E85(00)069088		
Oobloyah Valley, Ellesmere Is.	Univ. of Alaska	hydrologic budget, catchment areas, snow melt, sediment load	
Oobloyah Valley, Ellesmere Is.	Univ. of Alaska	hydrologic budget, catchment areas, snow melt, sediment load	

Basin	Organization	Data Collected	Problems/ Potential
Oobloyah Valley , Ellesmere Is.	see RE 3 E85 (00):069088		
Peace R.(B.C.)	B.C.Hydro and Power Authority(1979)	hydromet, hydro. mod els, probable max. precip., design floo d, snow	probable max. pre cip.
Pembina R.	Can.Plains Research Cen tre, Regina(1983)(UofR)	geog., hydrology, wa terflows, statistica l	
Pembina R.(Man.)	Can.Plains Research Cen tre, Regina (1983)(UofR)	geog., hydrology, wa ter flows, statistic al	
Peyto ck., Amis kwi R.(Alta.)	Geog.Dept.U of Man.(1981)	alpine, snowmelt, so luted, flow disch.,h ydrochemistry water quality	
Poplar R.(Sask.)	Int.Poplar R.Water Qual ity Board	hydrology, hydrogeol ogy, water quality, mine drainage	groundwater model ling analyses
Poplar R.(Sask. -Man.)	Poplar R. Ta sk Force	water use, groundwat er use, historic use , hydrologic analyse s, irrigation, reser voir evap.	flow apportionmen t
Porcupine R.,Pe el R.,Ogilivie R.,Big ck.- Tom ck.	Ind.Affairs & North.Dev. (1976)	hydrology, channel morphology, hydraul ics watershed	baseline hydrolog ical and morpholo gical info on riv ers
Prairie Provinc es(Souris R,Sas k.-Nelson)	PFRA(1978)	runoff, hydromet sta tions, streamflow, I.H.D.	
Prairies	Div.Hydrol. U of S	hydrology, snow cove r, meteorology, melt water eq., albedo, forecast models, str eam flow production	estimating areal snow water equiva lent in the prair ie environment

Basin	Organization	Data Collected	Problems/Potential
Prairies(Alta.)	N.W.Hydraulic Consulting (1978)	water yield, mgmt., clear cutting, runoff, hydrology, literature view	effects of forest cutting and management schemes
Rainbow ck.	F.F.Slaney Co.(1973)	planning, bridges, Mackenzie Hwy., env. effects, hydrology	basic env.data
Raven L.(NWT)	U of Georgia (1977)	Karst, geomorphology, hydrology, groundwater, flooding	
Red River	Fish and Env. Canada, AES (1977)	1800-1975, meteorology, agroclimatology, forecasting crop season, weather patterns	agricultural weather in Red River basin
Red River	Lombard North Group, Winnipeg(1975)	environment, diversion discharges, flooding, water quality, hydrology, fish and wildlife	Garrison diversion project
Resolute (NWT)	Geog.Dept.McMaster Univ. (1979)	hydrology, snowmelt, ? regimes, precip., runoff, streamflow	examine hydrologic behavior of ? regime basins
Resolute (NWT)	Geog.Dept.McMaster Univ. (1979)	water balance, precipitation, snowpack, hydrology, storage, spring melt	water balance of small lake
Resolute(NWT)	Dept.Geog. McMaster Univ. (1979)	hydrologic models, climate data, snowmelt, physical models, arctic basins	physical model to simulate snow storage in small arctic basin
River between Two Mts.	F.F.Slaney Co.(1973)	planning, bridges, Mackenzie Hwy., env. effects, hydrology	basic env.data
S.Sask.R.	Env.Canada and Sask.Water Corp.(established 1989)	geography, water resources, water use, management	

Basin	Organization	Data Collected	Problems/Potential
S.Sask.R.	Env.Canada, Water Survey Canada	precip., runoff forecasting, snowmelt, water supply, soil moisture, hydromet and hydrographs	basic env.data
S.Sask.River Basin	Env.Canada and Sask.Water Corp. (est.comp.1989)	geography, water resources, water use, management	
Saline R.	F.F.Slaney Co.(1973)	planning, hydrology, env.effects, soils, fisheries	
Sask-Nelson R.Basins	article for Canadian Water Resources Journal (1981)		
Sask.- Nelson R.	Alta. Env.(Planning Div.)(1982)	environment, hydrology, water qual., wildlife, Montana method, flow analysis, & gaging stations	
Sask.- Nelson R.	article for Canadian Water Resources Journal(1981)	geog.,water resources, env.impact, dams, water supply, diversions, water control	
Sask.-Nelson R.	Alta.Env.(Planning Div.)(1982)	environment, hydrology, water qual., wildlife, Montana method, flow analysis and gaging stations	
Sask.-Nelson R.	AES, Env.Canada	flooding, met.data, runoff, snowmelt, precip., temp., melting	
Sask.R.	Alta Env.(1977)	geog., rivers, hydrology classification	

Basin	Organization	Data Collected	Problems/ Potential
Sask.R.	Dept.Env., Water Survey s, AES(1974)	precip., streamflow, forecasting, floods, meteorological inter pretation, regressio n equations, storm rainfall analysis	1.determine metho d to compute natu ral flow for appo rtionment 2.strea mflow forecasting methods
Sask.R. - Nelso n, R.	Prairie Prov .Water Board	water mgmt.,demand supply, use, power generation, etc.	
Sask.R.,Bow R.	Water Survey of Canada(19 77)	flood frequency, sno w melt floods, flood frequency analysis	analysis of 2 fam ily population fl oods by using ske w coefficients
Sask.R.-Nelson R.	Prairie Prov . Water Boar d (1982)	water mgmt, demand, supply, use, power generation, etc.	
Sask.R.Basin	Alta.Environ ment (1977)	geog., rivers, hydro logy, classification	
Saskatchewan	Env.Canada, Inland Water s Dir.(1979)	flood damage, method ology, hydrology, ex penditures programs	1978-79 Canada-Sa sk. Flood Damage Reduction Annual Report
Saskatchewan	Div.of Hydro . U of S(197 6)	parametric hydrology , hydr.models, snow accum., ablation, cl imatic data streamfl ow	Modified Stanford IV - Snow accumul ation and Ablatio n model
small alpine wa tershed(B.C.)	U of B.C.(19 78)	mass and energy bala nce of small alpine watershed, measureme nt of snow ablationl , meltwater, snowpac k, runoff and energy balance at snow surf ace	
small High Arct ic (Resolute,NW T)	Geog.Dept.Mc Master Univ.	meteorology, precip. , topography, snow depth, streamflow, snow surveys	analysis of error in determination of snow storage for small arctic basins

Basin	Organization	Data Collected	Problems/Potential
Small prairie watershed	Ag.Engineering, U of S (1984)	Agric.engineering, drainage basins, stream discharges (Man. Sask.Alta.)	
Small prairie watershed	Ag.Eng., U of S(1964)	agric.engineering, drainage basins, stream discharges, (Man. Sask.Alta.)	
Souris R, Yellow Grass Marsh, Wascana ck.	Sask.Env.Hyd.Br.(1978)	hydrologic effects, hydro-met. stations, runoff, flood flows and damage, flood routing	effect of drainage development on flood flow at points of entry to the Souris R.
Souris R.	Env.Canada, Inland Water Dir.(1974)	water resources, land - human and natural resources, agriculture, engineering, hydrology, flooding control, planning mgmt.	update on inventory of Souris R. basin reference manual
Souris R.	Env.Canada, AES Hydromet. Centre(1978)	snow surveys, meteorology, drifting, snowpack, ground measurements, airborne surveys, Gamma radiation	analytical expression to correct under estimation of snow cover by attenuation of natural gamma radiation
Souris R.	U of N.Dakota(Aug./79)	snowmelt, hydrology, meteorology, climatic data fluctuations	snowmelt hydro-meteorology
Souris R.	Souris River Basin Study(1978)	hydrologic investigations, flood analysis, water quality, flood damage reduction	analysis of floods in Souris R. basin in Man. and Sask.
Spring ck. watershed(Alta.)	Alta.Env.Hyd.Br.1975	snowmelt, streamflow, snowpillow, climate, radiation, precipitation, hydrology	accurate estimation of daily snowmelt essential in streamflow forecast models
Steep ck.	F.F. Slaney Co.(1973)	planning, hydrology, env.effects, soils, fisheries	basic env.data

Basin	Organization	Data Collected	Problems/Potential
Subarctic region	Fenco Consultants(1976)	runoff, peak runoff simulation, discharge, snowmelt, meteorology, precip. regression analysis	peak flow simulation
Syncrude, Tar Sands(Alta.)	Syncrude Canada(1975)	hydrology, flood prediction, precip., topo., vegetation, hydrographs	flood frequency prediction for Syncrude Lease 17
Taglu-Richards Is., Mackenzie Delta	F.F.Slaney(1973)	meteorology data, inversions, northern dev., oil and gas	
Teslin R., Yukon R., Big Salmon R., Stewart R.	Dept. Ind. Affairs & North Dev.(1975)	hydrology, channel morphology, hydraulics, watershed	baseline hydrological info on rivers
Tri Creek (Alta.)	See 48/RNRE 850132		
Tri-Creek (Alta.)	see 3/RNRT 850190		
Tri-Creek watershed	Alta. Res. Council(1984)	computer appli.	
Tri-Creek watershed	Alta. Res. Council (1984)	computer applic.	
Twisty ck.(Mackenzie Mts.NWT)	Env.Canada, Glaciology Div.(1974)	precip., runoff, sediment, discharges	study relationships among precip., runoff, and erosion
Twisty ck.(Mackenzie Mts.NWT)	Env.Canada, Glaciology Div.(1974)	precip., runoff, sediment, discharges	study relationships among precip., runoff and erosion
U.B.C. research forest(Haney B.C.)	U of B.C.(1978)	storm flow, hydrogeology, soils, hillslopes hydrology	

Basin	Organization	Data Collected	Problems/Potential
West Montreal Lake plain(Sask.)	U of California	hydrologic cycle, clear cutting, forested, snowmelt, soil water, hydrographs, stream flow	determine importance of sub-surface flow and drainage, and effects of clear cutting on hydrologic cycle
Wilson CK Watershed	University of Manitoba (April/83)	rainfall VS elevation	Pot.: est. rainfall patterns based on elevation
Wilson ck.	Man.Dept.Nat.Res.(1957-82)	geog., drainage basins, (1950's, 60's, 70's, 80's)	
Wilson ck. (Man.)	U of Man. (1970)	water chemistry, hydro., ground water, surface water	
Wilson ck. watershed	Univ. of Manitoba (Apr./83)	rainfall vs elevation, Wilson ck-Manitoba Escarp.	Pot:est.rainfall patterns based on elevation
Wilson ck.(Man.)	Uof Manitoba (1970)	water chemistry, hydro., grd.water, surface water	
Wilson ck.(Man.)	Man.Dept.Nat.Res.(1957-82)	geog., drainage basins (1950's, 60's, 70's, 80's)	
Wood Buffalo Nat. Park	Airphoto Analysis Assoc. (1979)	Biophysical Ins., remote sensing, geol., soils, vegetation, climate hydrology, mapping	interdisciplinary reconnaissance level
Atim ck.(Alta.)	Alta.Env.(1978)	floods, lagoons, storm runoff, ground water, hydrology, agricultural flooding	identify extent of agric.flooding and solutions
Chilliwack R.(B.C.)	Geog.Dept., UofS(1983)	stochastic models, frequency of high flows, flooding, snowmelt and rainfall generated floods	stochastic models expanded to accommodate mixed generating processes

Basin	Organization	Data Collected	Problems/Potential
Chilliwack R.(B.C.)	Geog.Dept. UofS (1983)	stochastic models, frequency of high flows, flooding, snow melt and rainfall generated floods	stochastic models, expanded to accommodate mixed generating process
Fraser R.(B.C.), McGregor R.	Civil Eng., U of B.C.	snowmelt, rainfall, runoff and flow models, computer programs, stream flow forecasting	snowmelt and rainfall runoff model
Lee ck.(Alta.)	Alta. Envir. (1984)	soil moisture data, precip. sampling, vegetation water consumption by plants	water balance study
Mackenzie R.	Shawinigan Eng.Co./Dept. Ind.Affairs & Nor.Dev.(Jan/77)	hydrology, hydro-morphology, streamflow forecasting, flood forecasting, chemical morph	relationship between hydrology and hydro-morphology characteristics of streams
Mckenzie R.	Can.Climate center, AES Downsview(1983)	climatology, networks, precip., temp., meteorology, network design, weather stations	large scale assessment of monthly temp. and precip networks
Mckenzie R.	Can.Climate center, AES Downsview (1983)	climatology, networks, precip., temp., meteorology, network design, weather stations	large scale assessment of monthly temp and precip network
Milk R.(Alta.)	PFRA, AG Canada(1980)	river basin dev., dam const. reservoirs, hydrology cost	engineering study
Sask-Nelson R(Sask.Man.Alta.)	Env.Canada, Inland Water Dir.	water resources development, hydrology, flooding, reservoirs, simulation models	effect of regulation on Lake Winnipeg and Nelson R. as well as determine potential additional supply for diversion

Basin	Organization	Data Collected	Problems/ Potential
Southwestern B. C.	Cheng, J.D., Conference on Flash Flo ods(1978)	neteorology, hydrolo gy, hydrographs, sto rm flows, intensity	
Yukon R.	Underwood Mc Lellan Ltd/E nv.Canada, Inland Water s(1983)	flooding, hydrology, flow peak, flood for ecasting, protection	overview of flood prone areas, caus es, control and benefits
Yukon R.	Underwood Mc Lelland, Env .Canada, Inl. Waters(1983)	flooding, hydrology, flow peak, flood for ecasting, protection	overview of flood problem areas, ca uses, contrasts and benefits

APPENDIX C
INPUT DATA CHARACTERISTICS

Sensor	Attribute	Area	Use/Accuracy/Cost
Airborne low altitude (600 m)	thermal IR	< 1300 km ²	SWE r - 0.8 soil moisture r - 0.85
Landsat MSS	snow cover	> 25 km ²	point accuracy 0.62 gross accuracy 0.98
	land cover		point accuracy 0.62 gross accuracy 0.92
NOAA AVHRR		> 200 km ²	\$300/image
GOES			SWE $\pm$ 18.4% on 4 x 4 km grid
gamma survey	$\pm$ 10 mm	3000 km ²	rain r = 0.73 S.D. 0.36 mm 17 mm snow pack water equivalent
Radar		100 km ²	\$338/ line mi. $\pm$ 10-20% time integration 3 h 1 gauge every 3000 km ² collection freq. 6 h precip. rate > 1 mm/h
DCP			\$500/month connect charge \$10,700/y

Data collection network deficiencies:

- . inadequate precipitation gauge density prevents adequate determination of mean areal precipitation and degrades forecast accuracy and lead times. Many storms are not detected.
- . once-a-day sampling interval of precipitation and streamflow is not adequate to provide lead times for headwater floods.
- . reports from cooperative observers do not always forecast models representing as much as 70% of the precipitation.
- . large delays in data collection, due to manual data handling reduces warnings.
- . not enough real-time data is on the network to make decisions on flood forecast.

APPENDIX D
TYPES OF DATA REQUIRED

rainfall/runoff

precipitation
interception
infiltration
evapotranspiration
overland & open channel flow
subsurface flow
rainfall intensity

snow melt/runoff

aggregation
snow accumulation
runoff
infiltration
evaporation
infiltration
albedo
cloud amount

precipitation

rain
snow
time & space variation

interception

vegetation capture
wind velocity
storage capacity

infiltration

soil properties
initial water content
precip. rates
surface sealing
layered soils
movement of soil air
Horton Eq'n.
Philip Eq'n.
Holton Eq'n.
Green-Ampt model

continued

evapotranspiration

solar radiation
air temperature
vapour pressure
wind

overland flow

transfer function
lumped parameter
distributed parameter

subsurface flow

un-saturated flow
saturated flow

snow melt

variable

input

absorbed short-wave radiation

duration of sunshine

long-wave radiation

diurnal temperature range

convective heat exchange

air temperature for heavy forested areas
open area estimation

$(T_a - T_b)V$ where T_a is air temperature,
 T_b is snow surface temperature
 V is wind speed

heat of condensation

$(e_a - e_s)V$ where e_a and e_s are vapour
pressure of air and snow surface

APPENDIX E
FORECASTING SYSTEMS PRESENTLY IN PLACE

AES is presently issuing 5-day meteorological forecasts of air temperature and precipitation could be extended to 10 days. AES is also processing near real-time water budgets for approximately 300 synoptic stations across Canada and northern U.S.A. The water budget technique is based on the Thornthwaite model using daily temperatures and precipitation observation as input. Derived components from the model are estimates of evapotranspiration, soil moisture, snow pack water equivalents and snow melt. These water budget components are accumulated and averaged over a seven-day period and provided in tabulated and map form. Because these are available within 36 hours after the end of each seven-day period, they are particularly useful in climate monitoring and for supplying those economic sectors requiring climate information.

The production of quantitative precipitation forecasts and probability of precipitation amount forecasts are required but these have problems with the synoptic and statistical derivation. This requires skilled interpretation by the local forecast centre with their knowledge of local topography and meteorological phenomena. Beyond one day, the regional or general forecast is adequate but it must be recognized that forecasts for longer periods are usually less accurate.

The US National Weather Service produces a Limited Fine Mesh Model (LFM) while Canadian Meteorological Centre (CMC) runs a Spectral model. Both use the physics of the atmosphere to describe the present and future states but the CMC uses spherical harmonics series expansion of up to 29 waves to extrapolate to future time steps. Because both methods produce different outputs for the same input data, problems occur close to the USA/Canada border and experienced forecasters should be consulted. Each centre puts out Quantitative Precipitation Forecast Maps (QFP)

for 12 hour periods up to 48 hours. 120 hour forecasts are presently available but not distributed. Evaluation of the product shows that the maps have no bias (i.e. forecast precipitation occurred as frequently as actually happened). However, this results from over-estimating the occurrence of precipitation in the first 12 hour period and under-estimating in the subsequent three 12-hour periods (Hogg et al. 1985). In light rain situations, the forecast over-estimated and visa-versa for heavy rain. The forecast estimates the frequency correctly but under-forecasts the heavy rain which has serious implications for the hydrological forecaster and must be considered.

The Probability of Precipitation Amount (POPA) forecasts are produced twice per day for six consecutive 12 hour intervals for 72 stations. The probability of precipitation is given in three ranges: 0.2 to 2 mm; 2 to 10 mm; and greater than 10 mm. POPA forecasts range from 24% better than the climatology for a 12 hour forecast to only 8% better for a 60 hour forecast. The Western and Central Centres' POPA forecasts are the least accurate in the country (Hogg et al. 1985). The accuracies range from 12% and 18% at 12 hours to 2% and -5% at 60 hours. This was replaced by the Model Output Statistics (MOS) in 1986 and with better than 60% accuracy now available (Yacowar 1987).

The CMC forecasts of maximum and minimum temperature are made for a set of 160 stations out to day 5. Forecasts out to day 3 are transmitted twice per day, the longer range forecasts out to day 4 and 5 are transmitted once per day. The skill varies seasonally and geographically (generally higher in the east than the west and Arctic). The verification score used is percent improvement over climatology (percent variance explained). The score is given in Table 3.2.1. Fifteen-day

forecasts of temperature anomalies are prepared daily for 70 station using analog historic techniques. The products are produced by searching historic weather maps looking for similar case as the present one for the proceeding two weeks plus information supplied by the 500 mb 48 hour prognostic chart. After the best five sets are selected, the surface anomalies are calculated for the long term (in five ranges: much below normal to much above normal) (Hogg et al. 1985).

The CLI-Grid system is being developed on the CCAH Modcomp (7870) mini-computer (2 M byte of memory, 256 M byte disk drives, 2 Ramtek graphics displays, floating point processor, 4 tape drives, Talos digitizer) using the SATREP (Satellite Rainfall Evaluation Project) software as a base. Figure 3.2.1 shows a block diagram of the eventual operating system.

The use of radar information is not straightforward. Echoes coming from the ground targets as well as from anomalous propagation have to be detected and corrected. For non-automated (meteorological) purposes, these echoes are relatively easy to detect and remove. However for automated systems, the procedure is more complex. For example, normal echoes should not be higher than a certain rate or lead to gradients with neighboring echoes higher than a certain acceptable value. These must be determined on a regional and a seasonal basis (Hogg 1987). The resulting family of curves relating gradient values to a given probability of non-exceedance to close-by echoes and to the distance between echoes is considered to be a base value. The second step considers unwanted echoes on individual radar spheres. The radar data provides 24 hours of data with 6 hour accumulated data. The data is then structured to give mean basin amounts.